OECD ROAD TRANSPORT RESEARCH

STRAIN MEASUREMENTS IN BITUMINOUS LAYERS

REPORT PREPARED BY THE OECD/I 2
SCIENTIFIC EXPERT GROUP
PILOT COUNTRY: SWITZERLAND

ORGANISATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD)

PARIS, FRANCE

1985

SWISS FEDERAL OFFICE OF HIGHWAYS

BERNE, SWITZERLAND

OECD PROGRAMME OF CO-OPERATION IN THE FIELD OF ROAD TRANSPORT RESEARCH

This OECD Programme has two main fields of activity:

- International co-operation in road transport research to provide the technological support for Member countries' decisions on issues of highest priority. In the upcoming period these priority issues will comprise : a) construction, preservation and rehabilitation of road infrastructure; b) formulation and evaluation of integrated road and traffic safety programmes; c) development and improved management of road traffic control and driver communication systems; d) assessment of urban and interurban road transport system reforms; and e) the transfer of appropriate technologies to developing countries;

- Management and improvement of the information and documentation programme (IRRD - International Road Research Documentation), a co-operative scheme that enables the systematic exchange of information worldwide on scientific literature and current research programmes. Emphasis is laid on strengthening the documentary data base itself and on encouraging further use in developing countries.

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ABSTRACT

The OECD expert Group on "Full scale pavement tests" (Pilot country : Switzerland) organised a joint programme of strain measurements in bituminous layers. This field experiment was carried out in april 1984 on the test track of Nardò (Italy) with the participation of ten countries. Each of the participating teams used its own technique and its own material on a specially constructed test pavement with truck loadings. The strain gauges used are described and the test parameters have been analysed (properties of the pavement, of the vehicles, temperatures, etc.). In the comparison of the results analytical methods have been used together with field and laboratory data for the estimation of the true strain value. In view of the variability of a number of parameters the Group considers the methods adopted to be reliable and further international cooperation on this basis as possible.

RESUME

Le groupe d'experts de l'OECD "Essais en vraie grandeur des superstructures routières" (pays pilote: la Suisse) à mis sur pied un programme en commun de mesure des déformations au sein de couches d'enrobés hydrocarbonés. Cette expérience a été réalisée en avril 1984 sur la piste d'essai de Nardò (Italie) avec la participation de dix pays. Chaque équipe a utilisé sa technique et son matérial sur une même chaussée construite à cet effet, et chargée par des camions.

Une description des jauges de déformations a été faite et les paramètres de l'essai ont été analysés (caractéristiques de la chaussée et des véhicules de charge, température, etc.). Lors de la comparaison des résultats on a eu recours à des méthodes analytiques liées à des mesures in situ ou en laboratoire pour estimer la valeur effective de la déformation. Compte tenu de la variation de nombreux paramètres on peut dire que les méthodes utilisées sont fiables et qu'une collaboration internationale peut se développer.

ZUSAMMENFASSUNG

Eine Expertengruppe der OECD über "Grossversuche für den Strassenoberbau" (Pilotland: Schweiz) hat gemeinsame Versuche zur Messung von Dehnungen in bituminös gebundenen Schichten organisiert. Die Versuche fanden im April 1984 auf der Versuchspiste von Nardò (Italien) statt, mit der Teilnahme von 10 Ländern. Alle Teilnehmer haben auf einem speziell gebauten Versuchsoberbau mit Belastung durch Lastwagen ihre eigenen messtechnischen Verfahren und ihre Geräte gebraucht. Die verwendeten Messfühler werden beschrieben und verschiedene Versuchsparameter analysiert (Eigenschaften des Oberbaus, der Belastungsfahrzeuge, Temperaturen usw.). Beim Vergleich der Ergebnisse wurden auch analytische Methoden angewendet, um aufgrund von Feld- und Laborergebnissen die wahren Dehnungswerte zu schätzen. In Anbetracht der Streuung verschiedener Parameter können die verwendeten Methoden als zuverlässig beurteilt werden. Auf dieser Grundlage kann sich eine weitere internationale Zusammenarbeit entwickeln.

This report and the french version "Mesures de déformations dans des couches hydrocarbonées" may be obtained upon request from:

EPFL - LAVOC, CH-1015 LAUSANNE

ETHZ - IVT, Hönggerberg, CH-8093 ZURICH

This is a complementary report to the report "Full Scale Pavement Tests" prepared by the expert Group I 2 and published by OECD.

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Chapter I

INTRODUCTION

I.1 CO-OPERATION IN FULL SCALE PAVEMENT TESTING

Full scale (accelerated) pavements tests - usually carried out with some sort of traffic simulator like linear or circular test tracks, test pits with pulseload equipment - have had for a long time their well defined place in the pavement research programmes of different countries. As this type of test - besides its indisputable technical advantages - usually involves an important portion of the funds available for road research purposes, there is an absolute need for the best possible use of the results from the experiment itself and for well coordinated test programmes, in order to avoid repetition of tests already conducted elsewhere. The need for coordination in this field on an international basis was already recognised by OECD in the late sixties, with the creation of a group of experts and the publication of the report "Accelerated methods of life-testing pavements" in May 1972.

The decision to create a new Group followed after another OECD Group on the Impact of Heavy Freight Vehicles had noted the availability of a number of specialized large scale research facilities in member countries which were judged suitable for full scale testing of the behaviour of pavement structures and in particular the influence of heavy freight vehicles. The international Colloquium on Full Scale Pavement Testing held in May 1982 in Zurich also proved the existence of a large interest in at least a better exchange of information at a time when some new facilities were already at an advanced planning stage in different countries. Thus the new Group OECD RTR I2 "Full scale pavement tests" started its activity in March 1983 with Switzerland as the pilot country and active participation by delegates from Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the United Kingdom and the United States.

It is among the primary tasks of this Group to increase research benefits from the results of full scale pavement tests through an intensive international co-operation and coordination. This will only be possible when this has been established, and everybody uses the same technical language or, in other words, when the question of a possible direct comparison

of research results can be answered positively. Such an answer can be given once the comparability and reliability of measuring methods has been ascertained. A common or coordinated programme of measurements has therefore been considered as absolutely necessary (a "conditio sine qua non") for the further activity of the Group.

I.2 THE PURPOSE AND GENERAL CONDITIONS OF A PROGRAMME OF COMMON MEASUREMENTS

Possibilities of international collaboration are conditioned by the available test facilities (which are still frequently in use) and by the test methods employed. These test methods are the source of the principal problem: no laboratory can prove the absolute validity of the results of its measurements. This proof can only be obtained by common tests under the same conditions (structure, temperature, loading), where the results (strains and stresses) obtained by different laboratories will be compared. Two different situations may result from this comparison:

a.) the results are equal: in this case no doubt will remain about testing methods and techniques - international co-operation is then possible.

b.) the results are unequal: causes of the difference have to be found and contermeasures taken before the actual start of an international co-operation.

As it is practially impossible to solve at one time all different aspects of the problems outlined above, and also because such a programme, involving financial contributions from the participants to cover the general costs has not been attempted before, a procedure involving single steps has been adopted, with a limitation on the methods used for the measurement of strains in layers of bituminous concrete (these strain values are also quite important for the use of computer models of a pavement structure).

The purpose of this common programme of measurements is to verify the comparability of strain values measured with different technique (of measurement and data analysis) under the same boundary conditions (pavement, load, time and temperature) and with a sufficient number of single measurements.

As it is also believed that particular positioning techniques for the gauges can have a great influence on the results, it has been agreed that every participating institution will place the instruments using its own technique and personnel. By doing so, the test will provide not only the results related to the particular purpose of the programme but also an excellent opportunity for increasing the practical experience of personnel, who can familiarize themselves with different techniques.

I.3 PREPARATION AND ORGANISATION OF THE MEASUREMENTS

Following considerations concerning this programme as a very short term target in the Group's activity, the suitability of a particular testing site and its availability on the one hand and the cooperation provided by the Italian colleagues on the other, it was decided to organize this common programme of tests on the test track of Nardò in the south of Italy, where an experimental road has been added to a very large vehicle testing facility. On this experimental road a pavement length of 50 meters has been chosen for the common measurements.

The concept of the instrumentation had to follow the requirement of a sufficient number of single measurements for a particular loading condition (depending on the pavement structure, the dimension and magnitude of the loading time and the pavement temperature). Some of these variables were kept constant for the measurements:

- pavement structure: a homogeneous pavement section with constant thickness of crushed stone base

- load: 3 2-axle vehicles with same tyres and the same front and rear axle loads respectively

- loading time: only one testing speed of 30 km/h.

The general costs of the tests - to cover mainly the expenditure for the placing and compaction of two layers of bituminous concrete and the preparation of the loading vehicles and their use during the measurements - were divided among the participants. The operation had to be financed by contributions from the member countries of the Group through a special account administrated by OECD. Financial involvement of the participants in the common measurements also had to include all expenditures for material (strain gauges) and travel expenses to Italy for the engineers and technicians involved in the field experiment.

I.4 PARTICIPATION

All the delegations active in the Group participated in one form or another in this programme of common tests. The participants will be listed in the following under three different aspects:

- participation in the field test programme
- participation in the financing of the test programme
- participation in the data analysis work.

I.4.1 Participants in the field test programme

Nine teams from eight different countries participated in the test. They are listed here in alphabetical order (this order does not correspond with the numbering of the teams used in the rest of the report)

Australia : Australian Road Research Board, Nunawading, Victoria

Canada : Alberta Research Council, Civil Engineering Department, Edmonton, on behalf of Roads and Transportation Association of Canada. Gauges for installation in the test were also supplied by:

Saskatchewan Highways and Transportation, Research Branch, Regina

Denmark : Institute of Roads, Transport and Town Planning, The Technical University of Denmark, Lyngby

Finland : Technical Research Center of Finland, Road and Traffic Laboratory, Espoo

France : Laboratoire Central des Ponts et Chaussées, Nantes

Germany : Bundesanstalt für Strassenwesen, Bergisch-Gladbach

Italy : Società AUTOSTRADE, Rome and RODECO, Voghera

Switzerland: Laboratoire des voies de circulation LAVOC, Ecole Polytechnique Fédérale, Lausanne

Institut für Strassen-, Eisenbahn- und Felsbau ISETH, Swiss Federal Institute of Technology, Zurich.

The names of all the participants in the field test programme are given in annex D.

I.4.2 Participation in the financing of the test programme

Direct financial contributions to cover the general costs of the tests have been received from the following countries:

- Australia
- Belgium
- Canada
- Denmark
- Finland
- France
- Germany
- Switzerland
- U.S.A.

An important part of the general costs was shouldered by the Company AUTOSTRADE, Italy, which was also responsible for the local organisation.

The TRRL in the U.K. did all the detailed data analysis work free of charge using its own computing facilities.

I.4.3 Participation in the data analysis work

The work of analysing the data of the field results, reaching conclusions and preparing the present report was assigned to a subgroup of Group I 2, with the following participants:

- Belgium : J. Verstraeten
- Denmark : P. Ullidtz
- Finland : M. Huhtala
- France : A. de Boissoudy
- Germany : H. Buseck
- Italy : G. Battiato
- Switzerland : A.G. Dumont (Chairman), A. Jacot, I. Scazziga
- United Kingdom : R.R. Addis

I.5 CALENDAR OF EVENTS

- March 83, 1st meeting of the Group I 2: the idea is born
- May 2, 83, 1st draft technical programme
- September 83, 2nd meeting of the Group I 2: proposal to carry out the programme of measurements
- January 10, 84, meeting of the ad-hoc organisation group (Italian and Swiss delegations) at Voghera, Italy
- February 10, 84, deadline for announcement of participation
- March 6, 84, 2nd meeting of the ad-hoc organisation group at Bellinzona, Switzerland
- March 84, removal of old pavement at Nardò
- April 84, 2 - 6, placement of gauges and of the bituminous layers
  9 - 12, traffic loading tests and dynamic deflections
- June 12 - 13, 84, 1st meeting of data analysis sub-group, Bergisch-Gladbach (D)
- September 10 - 12, 84, 2nd meeting of data analysis sub-group, Crowthorne (UK)
- January 24 - 25, 85, 3rd and final meeting of data analysis subgroup, Stoos (CH)
- February 85, final draft of the report.

I.6 CONCEPT OF THE REPORT

This special report of Group I 2, additional to the Group's report published by OECD, gives in the following all detailed information on the joint programme of strain measurements carried out in April 1984 on the Nardò test site in Italy, and the subsequent work of data analysis and interpretation of the results. The conclusions of this report give on the one hand a summary and comprehensive interpretation of the results and on the other a series of recommendations. Detailed information on the gauges used and all the raw data from the test is included in graphical or numerical form in the annexes (Annex B and C).

Chapter II

TEST SITE AND TEST PAVEMENT

II.1 THE NARDÒ TEST SITE

The test track of Nardò - a ring road with a radius of 2 km - is one of the most important European centers for high speed and endurance tests of vehicles and trucks. The track is owned and operated by the Company SASN (Società Autopiste Sperimentali Nardò). This test facility is located in the south-east of Italy, near Brindisi. Fig. II.1 gives a general view of the Nardò test facility. The main ring of the Nardò track is divided into four lanes for cars and two lanes for trucks (see Fig. II.2).

In 1979 it was also decided to use the facility of Nardò for particular pavement tests. To this purpose an additional road was constructed inside the main ring. The total length of this road is approximately 1.8 km, including two 500 m connections to the ring and an available length of 800 m for experimental pavements. For the Italian road experiments carried out so far at Nardò 3 flexible and 1 rigid test pavement section have been constructed. With the arrangement chosen for the experimental road it is possible to use the vehicles circulating on the main ring as the loading for pavement tests. The direction of travel is normally changed every day on the main ring.

Plan and section of the experimental road are indicated in Fig. II.3.

II.2 THE TEST PAVEMENTS FOR THE OECD PROGRAMME

The area chosen for a new test pavement of the OECD common test programme is in the central portion of the experimental road. A total length of 40 m was constructed after partial removal of an existing flexible pavement (see Fig. II.4).

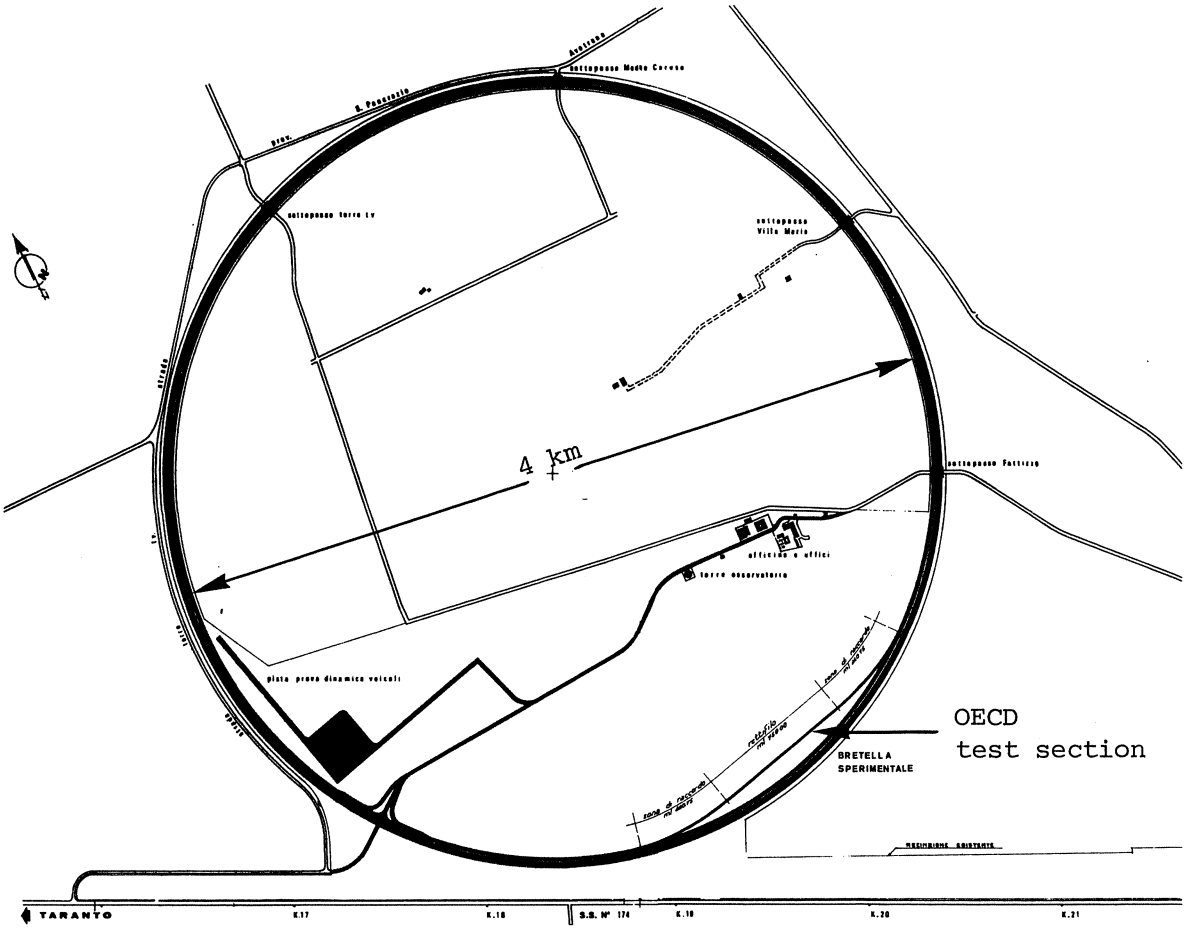


Fig. II.1 Plan of the apparatus of the SASN centre (Società Autopiste Sperimentali Nardò) with the new stretch containing the OECD pavement structure

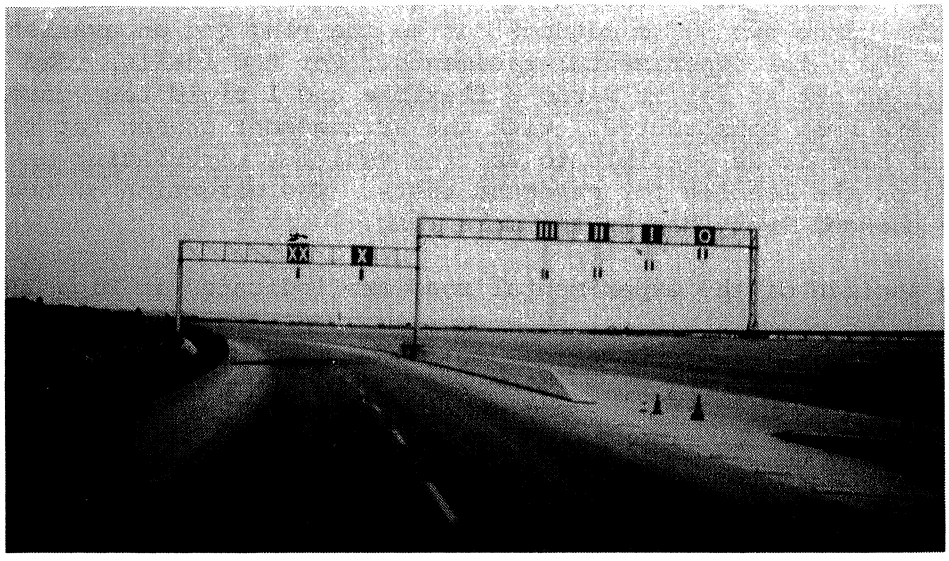


Fig. II.2 The principal ring of the Nardò track, divided into 2 lanes for freight vehicles and 4 lanes for cars, separated by a continuous "New Jersey" concrete barrier

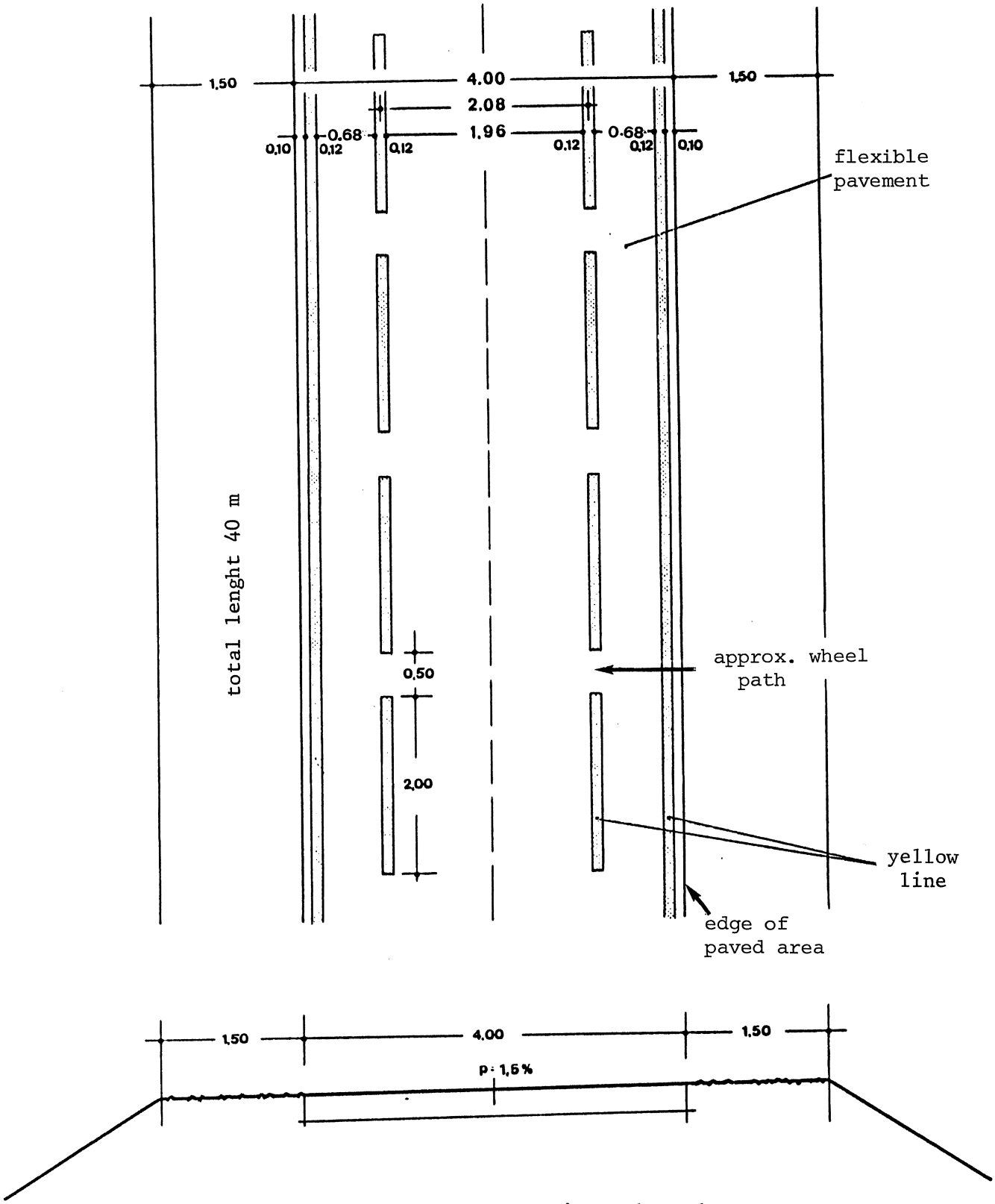


Fig. II.3 Plan and section of the experimental road

Construction of the OECD test pavement required the removal of the two existing layers of bituminous concrete and of the top of the crushed stone base. After grading and compaction of the crushed stone base with the reduced thickness of 170 mm one plate bearing test was carried out on its surface using a 300 mm Ø plate (test procedure according to Swiss Standard SN 670 317). For the first and the second loading cycles the following moduli were calculated on the basis of the differential settlement between loads of 0.25 and 0.15 MPa:

1. cycle: M_E = 137 MPa
2. cycle: M_E = 273 MPa

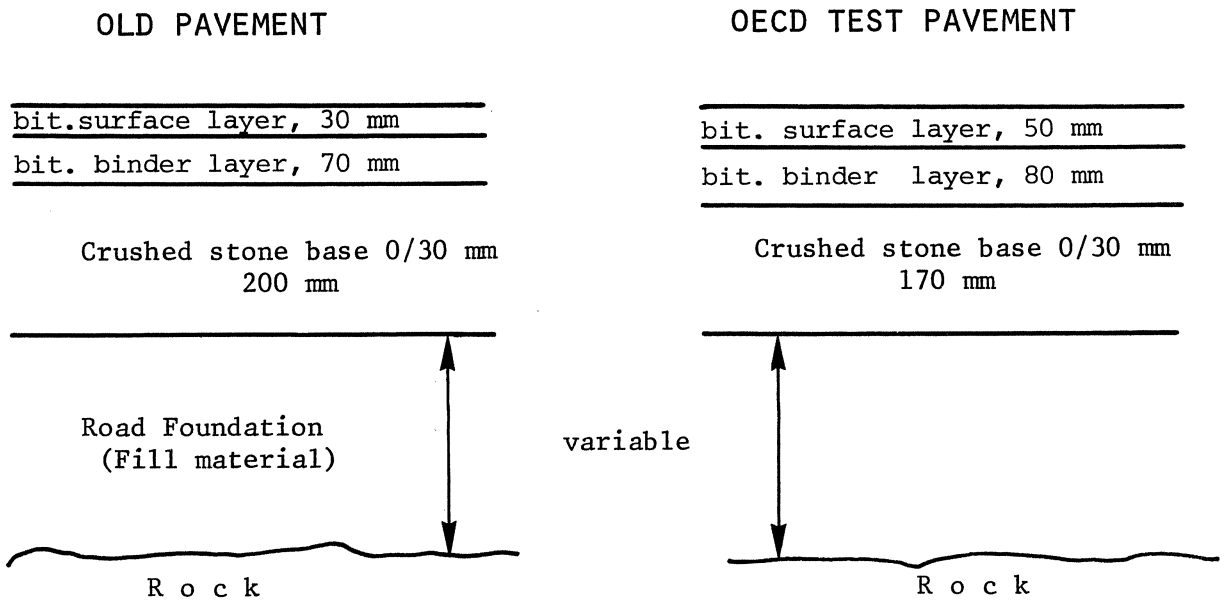


Fig. II.4 Pavement structures

These values characterize the crushed stone base as a relatively stiff material, a result which is also dependent on the presence of rock at a certain depth. On the other hand, the ratio of 2 for the moduli after the second and first cycles indicates that the compaction of the layer is only just sufficient and could potentially be improved.

The grading curve, composition characteristics and test results on the bituminous concrete and the binder are indicated in chapter IV.

During the placement of the bituminous concrete material special care was adopted in order to avoid damage to the strain gauges with

- a mix temperature not exceeding 130°C,
- the use of rubber tyre rollers
- and by not allowing vibratory compaction.

These precautions are the cause of the final high void content of the bituminous concrete.

Chapter III

STRAIN MEASUREMENTS

III.1 INTRODUCTION

Horizontal deformations inside bituminous concrete layers under the action of a given load are usually measured with strain gauges. These deformation sensors contain a thin wire under electric current. The electrical resistance R of the wire varies by $\Delta R/Ro$ upon a mechanical elongation $\varepsilon = \Delta L/Lo$. Thus we can write:

$$\Delta R/Ro = k \cdot \varepsilon$$

units: ΔR, R [Ω]

ε (10^{-6}m/m = microstrain)

The gauge factor k is a characteristic value of the gauge.

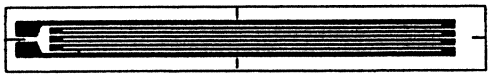


Figure III.1 Example of strain gauge

The mechanical deformation imposed on the gauge and its carrier material is transformed into electrical signals which can be quantified by means of a measurement unit, a Wheatstone bridge. An amplifier and a reading instrument (oscilloscope or graphical recorder) usually complete the data aquisition system. Improved systems allow automatic data storage on magnetic tapes or cassettes for later analysis purposes.

The cables connecting the gauge to the measurement unit have a small electrical resistance. Also temperature changes can vary the resistance of the gauge. Particular measures (full or half bridge, temperature-compensation gauge, short cables with large section) can help to limit these disturbing effects.

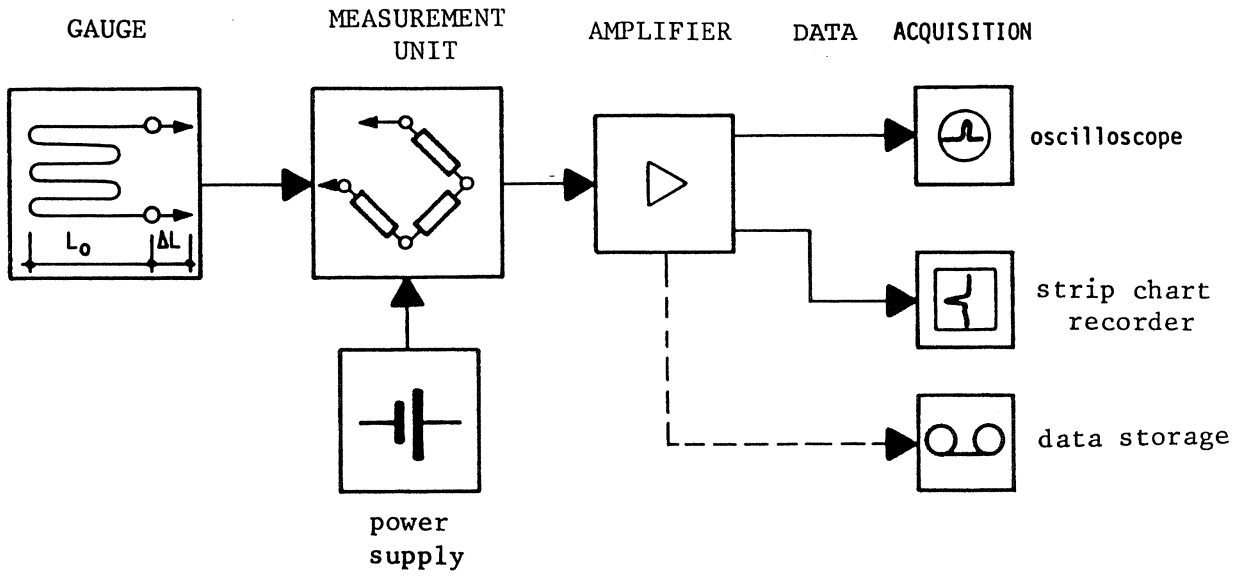


Fig. III.2 Data acquisition system

III.2 TYPES OF GAUGES

Gauges available on the market nowadays are usually not suitable for a direct measurement of deformations inside bituminous materials. Thus research institutions mostly assembly their own strain gauges, with the addition of supporting or anchoring elements. Interesting experiments have also been conducted in order to glue the foil directly onto the bituminous material, either onto a specimen prepared in the laboratory or onto a core taken from the pavement.

A classification into three main groups has been made on the basis of the mode of placement:

1. H-shaped gauges
2. Gauges glued onto bituminous materials from the laboratory
3. Gauges glued onto cores taken from the pavement.

These groups are then also subdivided according to the particular construction of the supporting element or the type of bituminous material. This classification is shown in Fig. III.3. Detailed information on each gauge is included in the data forms in annex C of this report.

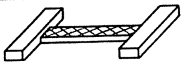
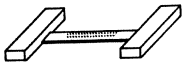
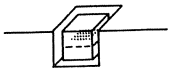
GROUP	SCHEMATIC CONSTRUCTION	GAUGE MODEL	ACTIVE LENGTH OF WIRE/ANCHOR	RESISTANCE (Ω)	COST (US $)	TEAM	ASSEMBLY
1.1		KYOWA KM-120-H2-11L 100-3	70 MM/104 MM	120 ± 1 %	40	3	- FIXATION OF ANCHOR BARS IN THE LABORATORY
		KYOWA KM-120-H2-11L 100-3	70 MM/106 MM	120 ± 1 %	35	5	
		KYOWA KM-120-H2-11L 100-3	70 MM/100 MM	120 ± 1 %	75	7	
1.2		KYOWA KC-70-A1-11	67 MM/130 MM	120	35	2	- GAUGE GLUED TO SUPPORT AND FIXATION OF ANCHOR BARS IN THE LABORATORY
		PL 30 ou KYOWA KFC-30-C1-11	30 MM/100 MM	120	23	6	
1.3		HBM DA 3	88 MM/140 MM	350	180	1	
2.1		HBM LP 21 60-120	60 MM/60 MM	120	12	1	- GLUED ON MARSHALL SPECIMEN CUT TO 1/3 HEIGHT
		BLH FAE 2-300-35 PL	76 MM/76 MM	350	35	8	- GLUED ON LABORATORY SPECIMEN
2.2		HBM 20/600 XA21	20 MM/20 MM	600 ± 0,25	10	9	- GLUED IN THE CENTER OF A LABORATORY SPECIMEN
2.3		METAL FOIL GAUGE	13 MM/25 MM	120	15	4	- GLUED ON A BLOC OF SHEET ASPHALT
3.1		HBM LP 21 60-120	60 MM/60 MM	120	12	1	- GLUED ON CORE TAKEN FROM THE PAVEMENT
		HBM 60/600 LP 21		600 ± 0,25	15	3	

Figure III.3 Classification of the gauges

In addition to the gauges described so far and shown in Fig. III.3, also a pair of Bison gauges were installed in the free space following the site of team No. 9 (see Fig. III.17). The two gauges were installed one after the other on the same line as the other gauges at the interface of the crushed stone base and the lower layer of bituminous concrete.

Group 1

For essentially historical reasons three teams (3, 5 and 7) use the same type of gauge (1.1), where the foil is enclosed in a bar of plastic material. At both ends aluminium bars are fixed for a better anchoring in the bituminous layers.

Two teams (2 and 6) have adopted the method recommended by TRRL: the foil gauge is glued on an aluminium stripe which itself has the same anchoring system (1.2). The central part of the gauge must be well protected.

Team no. 1 has used gauges specially designed for bituminous materials. These gauges do not need any preparation (1.3).

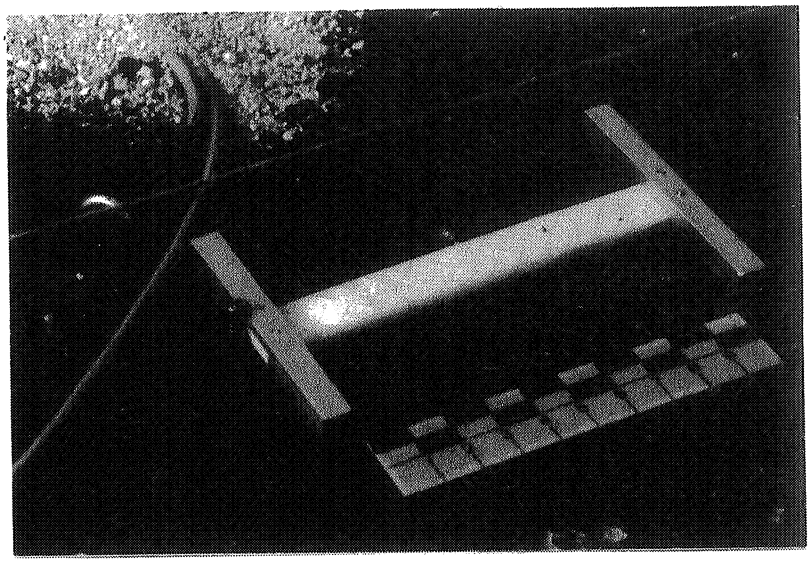


Figure III.4
Gauge type 1.1

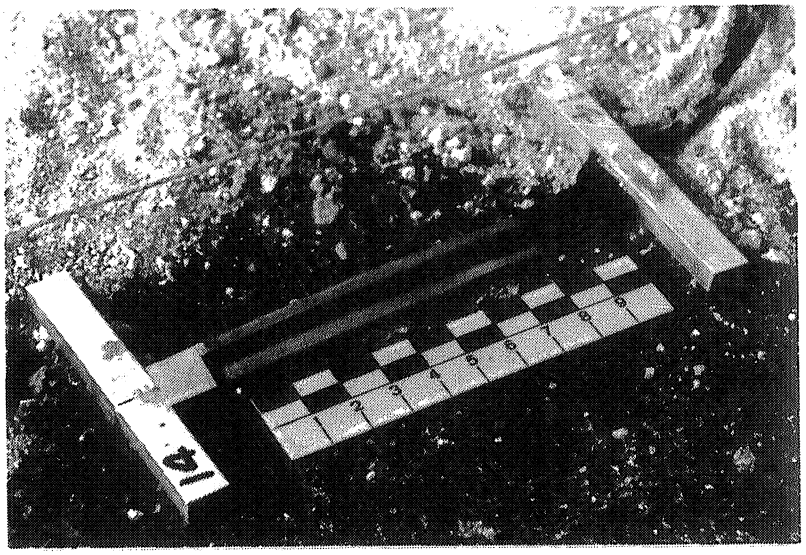


Figure III.5
Gauge type 1.2

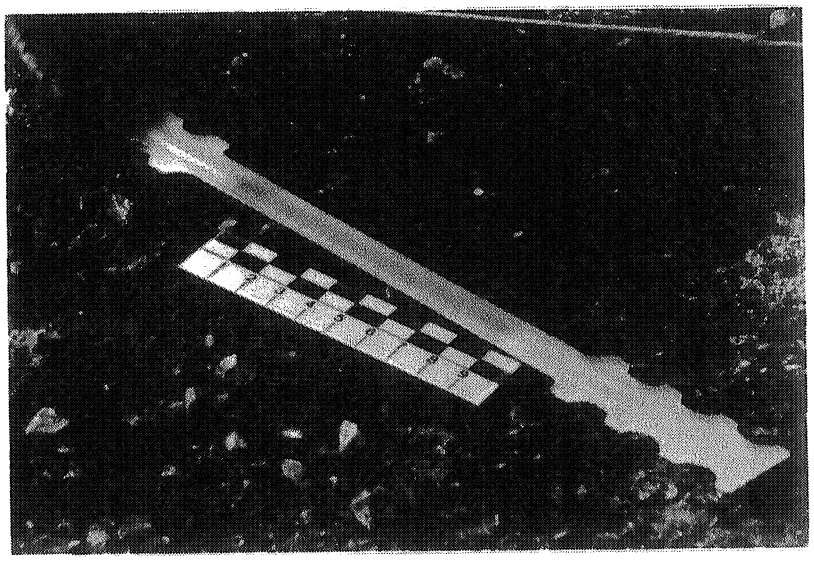


Figure III.6
Gauge type 1.3

Group 2

Four teams glue their gauges directly onto specimens compacted in the laboratory: Marshall specimens in the case of team no. 1 and cylindrical specimens of 160 mm Ø in the case of team no. 8 (2.1). Team no. 9 follows the Shell method and uses short foil gauges (20 mm) glued onto a block of bituminous mix cut and reglued together in the laboratory (2.2). Team no. 4 fixes its gauges within a thin plate of "sheet asphalt" of size 15 x 15 cm (2.3).

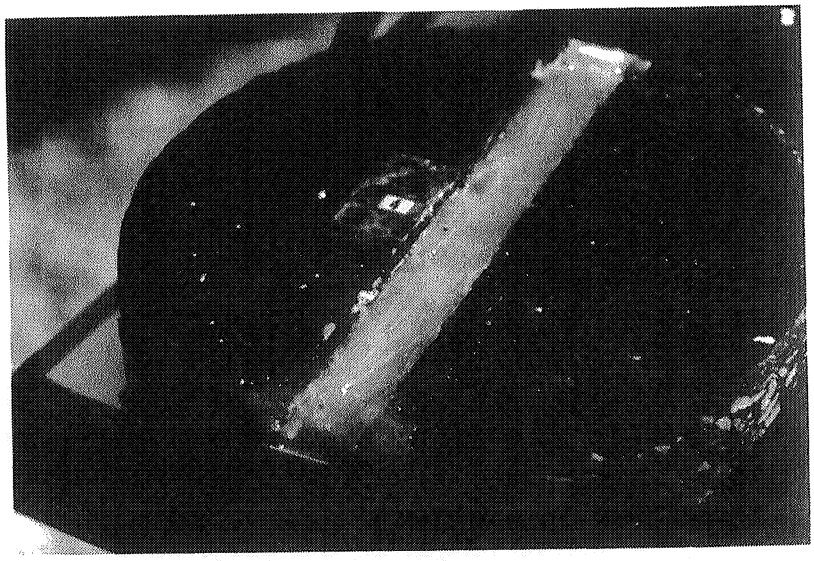


Figure III.7

Gauge type 2.1
(upside down,
before installation)

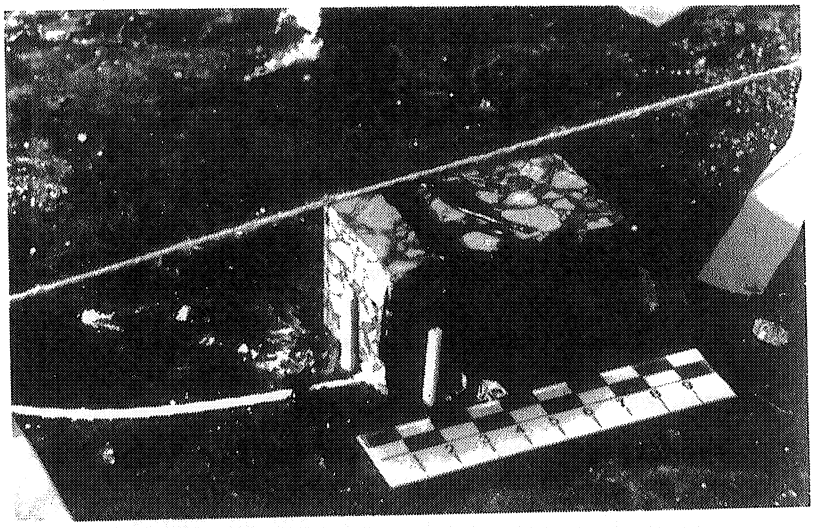


Figure III.8

Gauge type 2.2

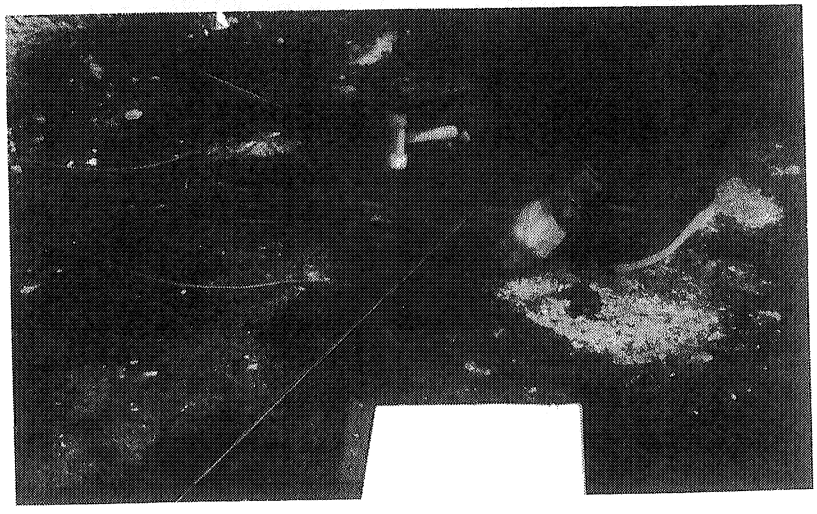


Figure III.9

Gauge type 2.3

Group 3

Two teams (1 and 3) take a core from the test pavement, fix one or two gauges (top and bottom) into it and reinsert the core in the borehole. The cutting space is then filled with epoxy resin.

Figure III.10

Gauge type 3.1 (upside down, before installation)

The active length of the gauge is different from the spacing between the anchoring bars. Some very short gauges (30 mm) are sometimes fixed on a support of 100 mm length. Although a German study indicates that the active length has only minor influence on the results, a length of about 3 to 5 times the maximum grain size should be preferred.

Electric resistances for the gauges come in just three different values of 120, 350 or 600 Ω.

From the point of view of prices, and without considering the labour costs of the research agencies for the preparation of the gauges, three different groups appear:

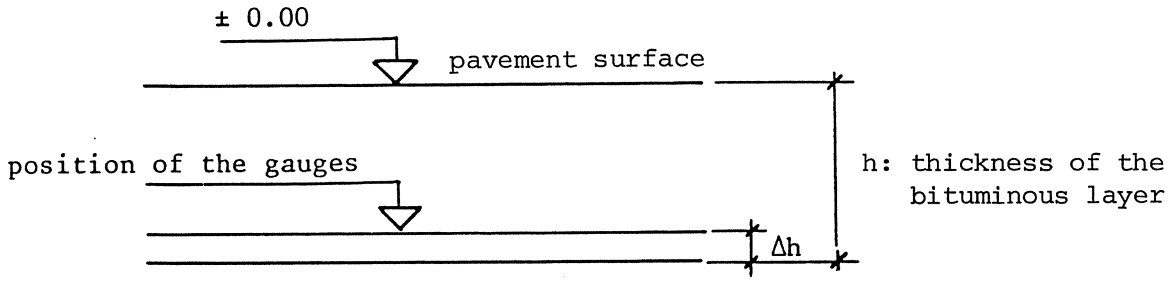
a.) gauges of groups 1.2, 2 and 3 — 10 - 35 US$

b.) gauges inserted in supporting element without anchoring bars, group 1.1 — 35 - 75 US$

c.) special gauge for bituminous materials, group 1.3. — 180 US$

III.3 LEVEL OF THE GAUGES

Depending on the type of gauge used and the mode of placement, the exact level of the gauge often does not correspond to the theoretical position at the bottom of the layer. On the basis of the information provided by the different teams, the following Δh values have been determined.



Gauge group	team no.	Δh [mm]	
1.1	3, 5, 7	2	
1.2	2	0	
1.2	6	4	
1.3	1	0	
2.1	1	0	
2.1	8	5	
2.2	9	0	upper layer
2.2	9	15	lower layer
2.3	4	6	
3.1	1	0	
3.1	3	11	

Figure III.11 Relative position of the gauges

III.4 CONDITION OF THE GAUGES

During placement and compaction of bituminous layers a certain number of gauges are destroyed or become useless. In the following table III.12, indicating the condition of the gauges before traffic loadings on April 8, 1984, gauge losses during construction (resistance equal to zero or beyond limits) and useless signals (disturbance of shape and maximum value) have been separated.

The results obtained are very much better than those which can usually be observed in full-scale tests with losses often in the range of 50 %. Different hypotheses can explain this result.

First of all, compaction of the test pavement was done without vibration and with the use of rubber tyre rollers. Moreover, the high void content and a low temperature during compaction have limited the displacements of the gauges relative to their cables and finally all teams have taken particular care in the placement of their gauges.

However, important losses were observed for team no. 2 using gauges of group 1.2. It is possible that the protection of the active part of the gauge was not sufficient. In fact, the same gauges placed in the upper layer with an additional aluminium plate protection worked quite well.

Equipe Team No.	1	2	3	4	5	6	7	8	9	Total
Couche sup. Upper layer	(201...234)									
Nb of gauges	2	8	16	0	16	12	13	4	8	79
Gauges OK	1	5	16	-	16	11	12	4	7	72
Gauges KO	1	3	0	-	0	1	1	0	1	7
Loss rate [%]	50	38	0	-	0	8	8	0	13	[9]
Signal OK	1	5	15	-	15	11	12	4	7	70
Signal KO	0	0	1	-	1	0	0	0	0	2
Loss rate [%]	0	0	6	-	6	0	0	0	0	[3]
Couche inf. Lower layer	101...134)									
Nb of gauges	17	16	16	4	16	16	16	8	8	117
Gauges OK	16	2	16	2	16	16	15	8	7	98
Gauges KO	1	14	0	2	0	0	1	0	1	19
Loss rate [%]	6	88	0	50	0	0	6	0	13	[16]
Signal OK	15	2	16	2	16	16	15	7	7	96
Signal KO	1	0	0	0	0	0	0	1	0	2
Loss rate [%]	6	0	0	0	0	0	0	13	0	[2]

Nb of gauges, total	196	100 %
OK	170	87 %
KO	26	13 %
Nb of gauges with signal OK total	166	[85 %]

Fig. III.12 Condition of the gauges before traffic loadings, April 8, 1984

The reduced number of loadings does not allow drawing any conclusions on the long term behaviour of the gauges (fatigue, durability). It is, however, known that other effects such as water infiltration, could cause a failure of the gauge. To this purpose, measurements of the electrical resistance were carried out in January 1985 on the test pavement. The results of these measurements are given in fig. III.13. After 9 months and in spite of the fact that the cables had not been specially protected the rate of losses is still low, generally below 15 %. The gauges of teams no. 4 had already shown 50 % of losses after construction of the pavement. On the other hand team no. 8, which had lost just one gauge in April 1984, has now lost almost all of its gauges. Some infiltrations of water along the cables which had been cut through at the pave-

ment edge (this is obviously not the normal case for gauges meant for future use) could explain why only 1 gauge out of 10 still has an electric resistance of 350 Ω.

Gauge category	1.1	1.1	1.1	1.2	1.2	1.3	2.1	2.1	2.2	2.3	3.1	3.1
Team no.	3	5	7	2	6	1	1	8	9	4	1	3
Electrical resistance												
nominal 1 [Ω]	120	120	120	120	120	350	120	350	600	120	120	600
max. meas. 2 [Ω]	133.2	122.1	122.4	122.6	121.4	379.0	125.9	356.9	604.5	120.8	121.6	602.3
min. meas. 2 [Ω]	118.8	119.5	119.7	120.8	119.8	346.7	121.1	356.9	596.2	120.7	121.0	599.8
No. of measured gauges	24	27	33	6	28	7	7	10	20	4	4	8
No. of gauges KO	0	4	1	0	1	1	0	9	3	2	0	0
% losses	0	15	3	0	4	14	0	90	15	50	0	0

Remark: The percentage of losses can be lower than the values indicated in Fig. III.14 if not all the gauges have been controlled.

1.) according to the given values for each gauge

2.) for the gauges with a resistance neither equal to zero nor infinite

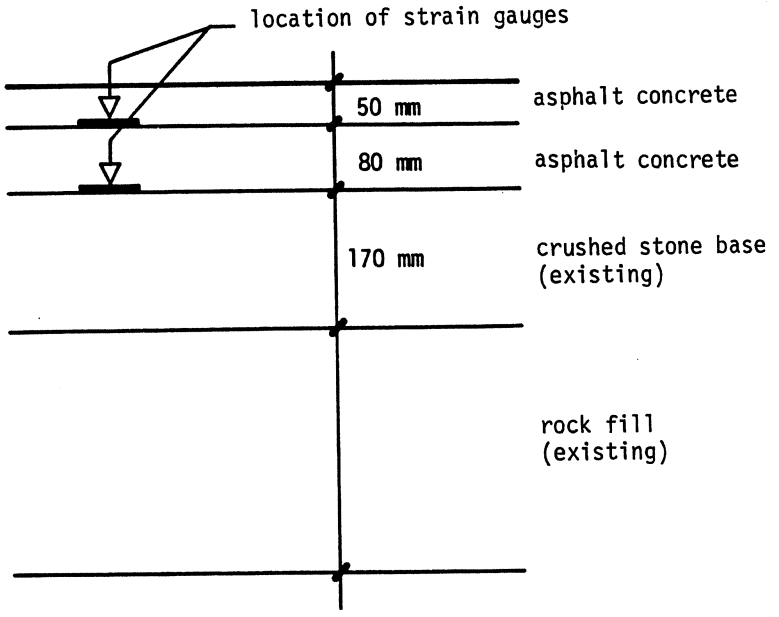
Fig. III.13 Electrical resistance of the gauges in January 1985, 9 months later

III.5 POSITION OF THE GAUGES

Gauges have been placed at two different levels in the pavement, i.e. at a lower level on top of the crushed stone base and at an upper level on top of the lower layer of bituminous concrete.

Figure III.14

Vertical position of the gauges



The horizontal disposition has been planned for a positioning of the gauges in the zone of load passages, trying also to avoid interference due to a high concentration of gauges. It should be kept in mind that a total pavement length of only 3 m was provided for each team.

The layout of all the gauges is shown in Figures III.16 and III.17 (lower layer only, as the results of the upper gauges are not discussed elsewhere in this report).

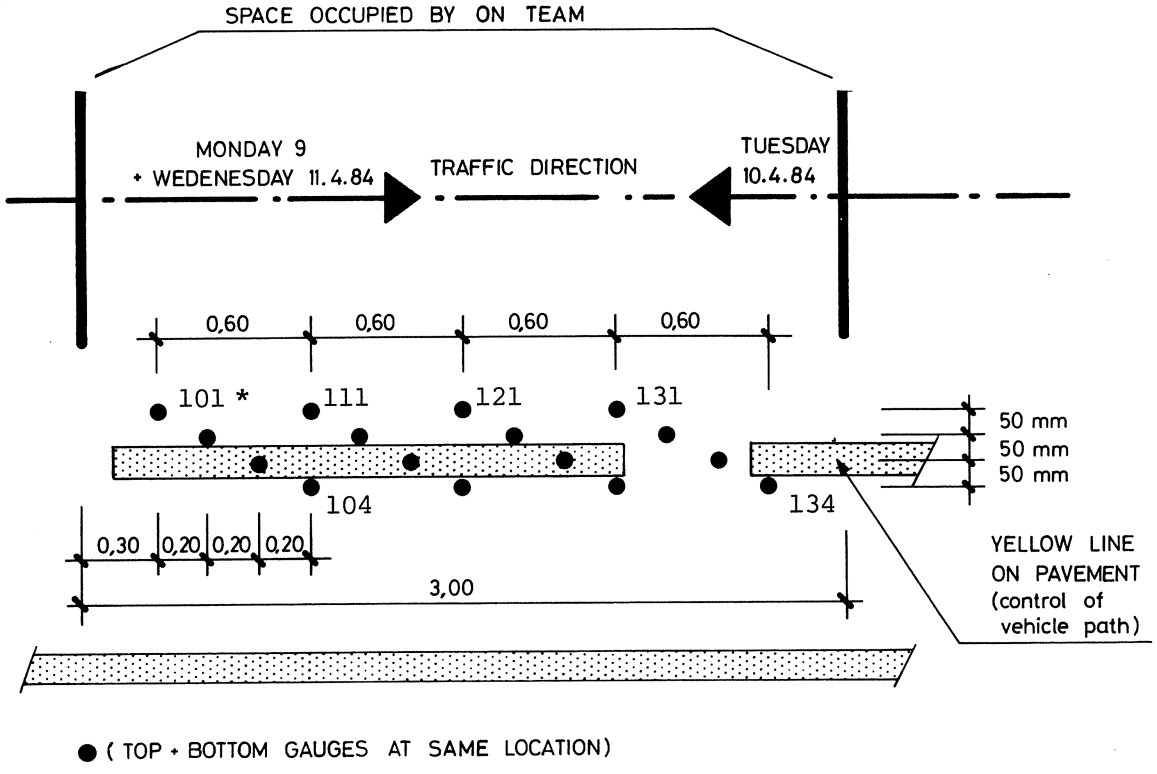


Figure III.15 Horizontal position of the gauges (*: numbering of the gauges)

Fig. III.16 **Lower layer gauges layout (No 101-134)**

Plan de pose des capteurs de la couche inférieure (no 101-134)

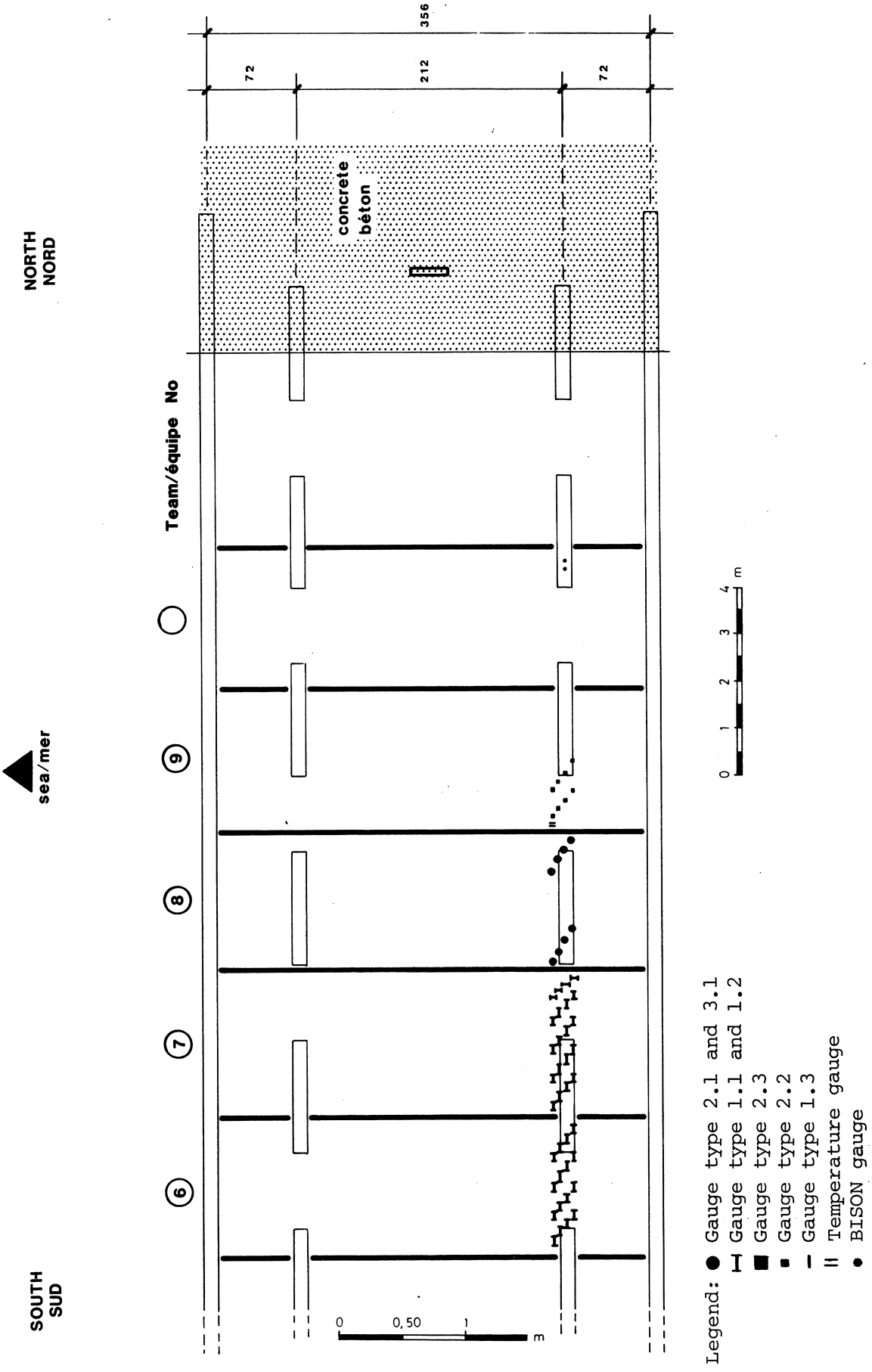
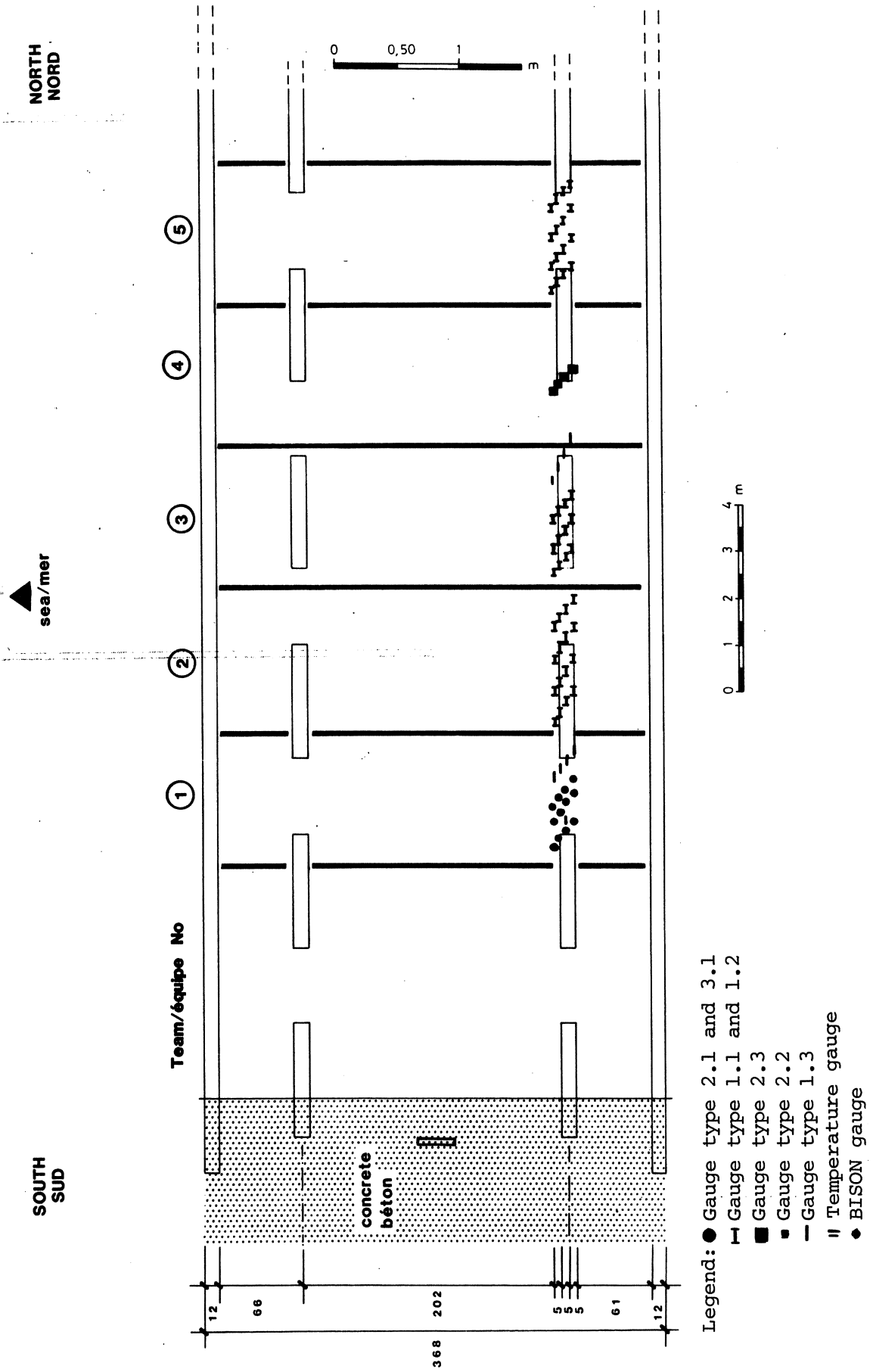


Fig. III.17 **Lower layer gauges layout (No 101-134)**
Plan de pose des capteurs de la couche inférieure (no 101-134)



Chapter IV

CONTROL OF THE TEST PAVEMENT STRUCTURE

IV.1 INTRODUCTION

As already indicated in Chapter II, the test pavement chosen for the OECD programme is only partially a completely new structure. In fact, only the two top layers of bituminous concrete (with a total nominal thickness of 130 mm) were newly placed for the test after removal of the upper part of the previous structure. In the following Chapter the results of different tests and measurements are given, which were carried out for the purpose of checking the homogeneous condition of the test pavement over its length.

Material investigations (layer thickness, granulometry, binder and void centent) were carried out on cores taken from the track after conclusion of the experiments. These cores were analyzed in different laboratories of some of the participating teams. In addition to a more common material analysis, also some "advanced" tests were conducted, the main purpose being to determine the modulus of the bituminous concrete.

The condition of the "existing" portion of the pavement, i.e. the granular base and the subgrade, was tested indirectly by means of two different dynamic loading devices. Dynamic deflection values reflect the behaviour of both the old (granular base, subgrade) and new (bituminous concrete) material together, but with accurate analysis some judgements on the lower portions only of the pavement structure are also possible.

IV.2 LAYER THICKNESS

The thickness of the layers has been determined in the laboratory from cores taken out of the test pavement. The results, given in detail in fig. IV.1, show the following values:

		min.	mean	max.
upper layer	[mm]	38	48	57
lower layer	[mm]	70	79	88
total	[mm]	117	127	138

all the values are also represented graphically in figure IV.2.

Analysing laboratory	BAST Germany			LAVOC Switzerland		
core number	upper layer	lower layer	total (mm)	upper layer	lower layer	total (mm)
1	50	88	138			
2	50	88	138			
3	52	82	134			
4	53	83	136			
5	57	80	137			
6	50	70	120			
7	44	78	122			
8	38	79	117			
9				50.3	75.7	126.0
10	44	78	122			
11				53.6	72.7	126.3
12				49.6	75.2	124.8
13						
14						
15						
16				51.7	77.0	128.7
17	41	82	123			
18	40	77	117			
19	50	81	131			

Figure IV.1 Thickness of the cores taken on the Nardò test pavement

IV.3 MATERIAL PROPERTIES

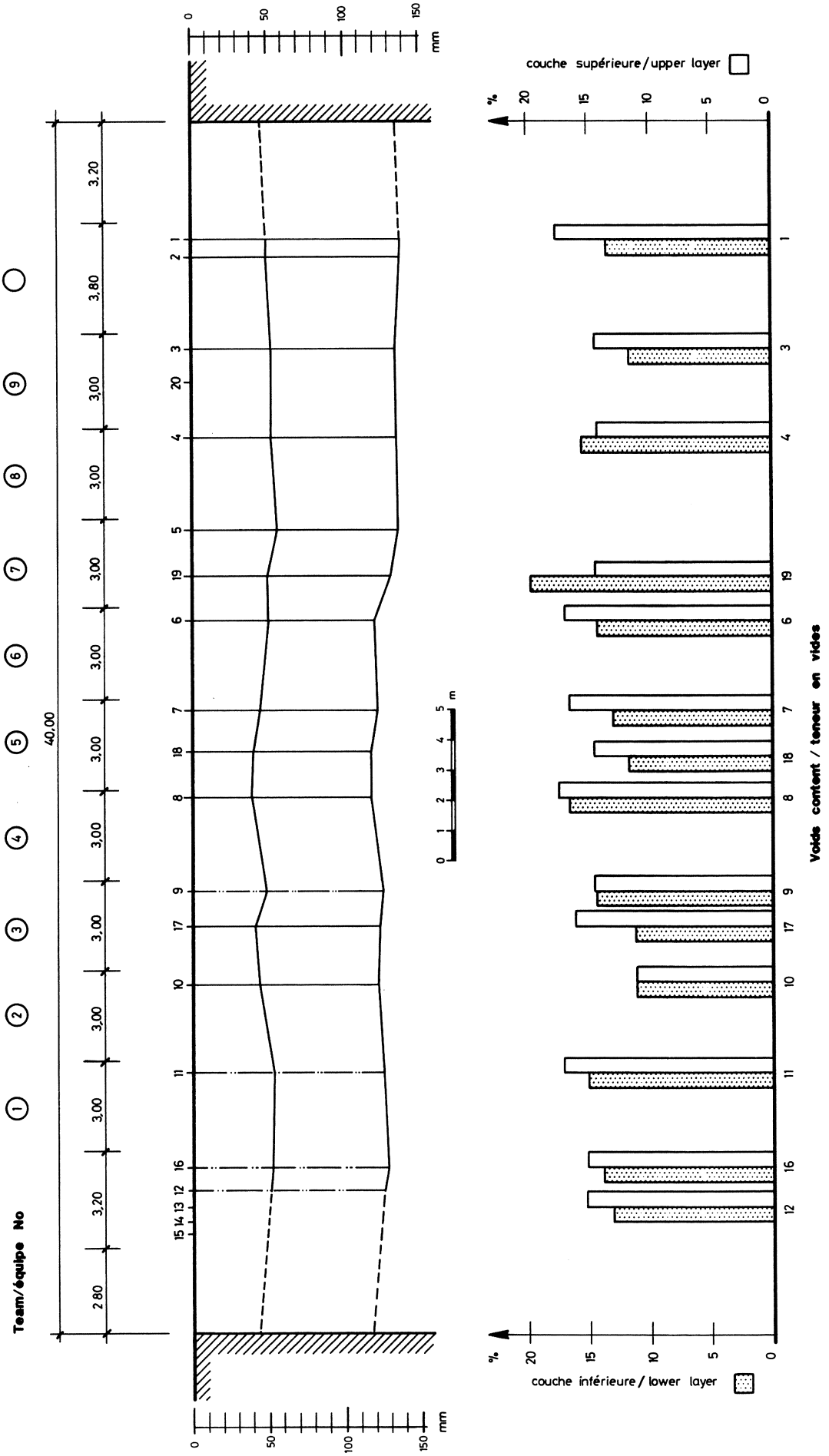
IV.3.1 Bituminous concrete

The bituminous mixes have been analysed in the laboratories of three research centers: CRR in Belgium, BAST in Germany and LAVOC in Switzerland.

The testing methods used and the location of the specimens are not identical for each laboratory. This can partially explain the differences in the determination of the void content (fig. IV.3).

Grain size distribution analysis gives only little information on the quality of the mix. However, it is noticeable that the specimen from the lower layer analyzed by CRR has a rich sand portion (figures IV.4 and IV.5).

Figure IV.2: Thickness of bituminous layers



laboratory	BAST		LAVOC	
core number	upper layer	lower layer	upper layer	lower layer
1	17.8	13.6		
3	14.6	11.7		
4	14.4	15.7		
6	17.1	14.4		
7	16.7	13.1		
8	17.6	16.7		
9			14.5	14.4
11			17.1	15.1
12			15.3	13.1
16			15.3	13.9
17	16.3	11.4		
19	14.6	19.9		

Fig. IV.3 Void content of the cores [%]

The binder content of both layers is shown in fig. IV.6:

laboratory	CRR	BAST	LAVOC	MEAN
Binder content [% of the mass of the mix]				
upper layer	3.99	3.70	3.92	3.87
lower layer	4.27	3.60	3.79	3.89

Fig. IV.6 Binder content

On the basis of these results it appears that the bituminous concrete placed for this programme of measurements is of poor quality and is inferior to the bituminous mixes normally used in road construction. In particular, void content values are very high, 16 and 15 %, while at the same time the binder content is very low: 3.9 %. The placement of a thin layer (down to 40 mm) and the prohibition of the use of vibratory rollers may partially explain these results. Further, a low mix temperature also influenced the final quality.

IV.3.2 Binders

Among the extracted binders, the one obtained by CRR in the upper layer has a rather low penetration value ($21 \cdot 10^{-1}$mm). An additional study by LAVOC on this particular binder shows a very marked rheological behaviour, the material being very viscous at low temperature and fluid at high temperature.

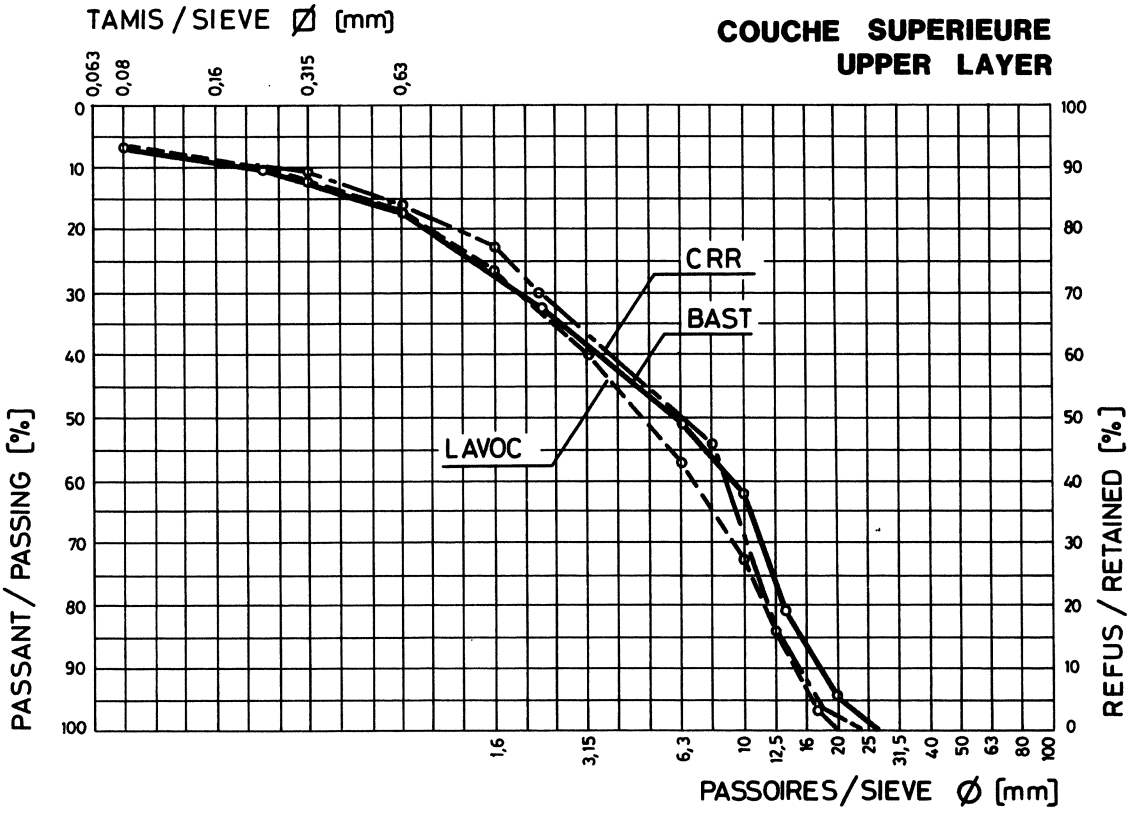


Figure IV.4: Grain size distribution of the upper layer

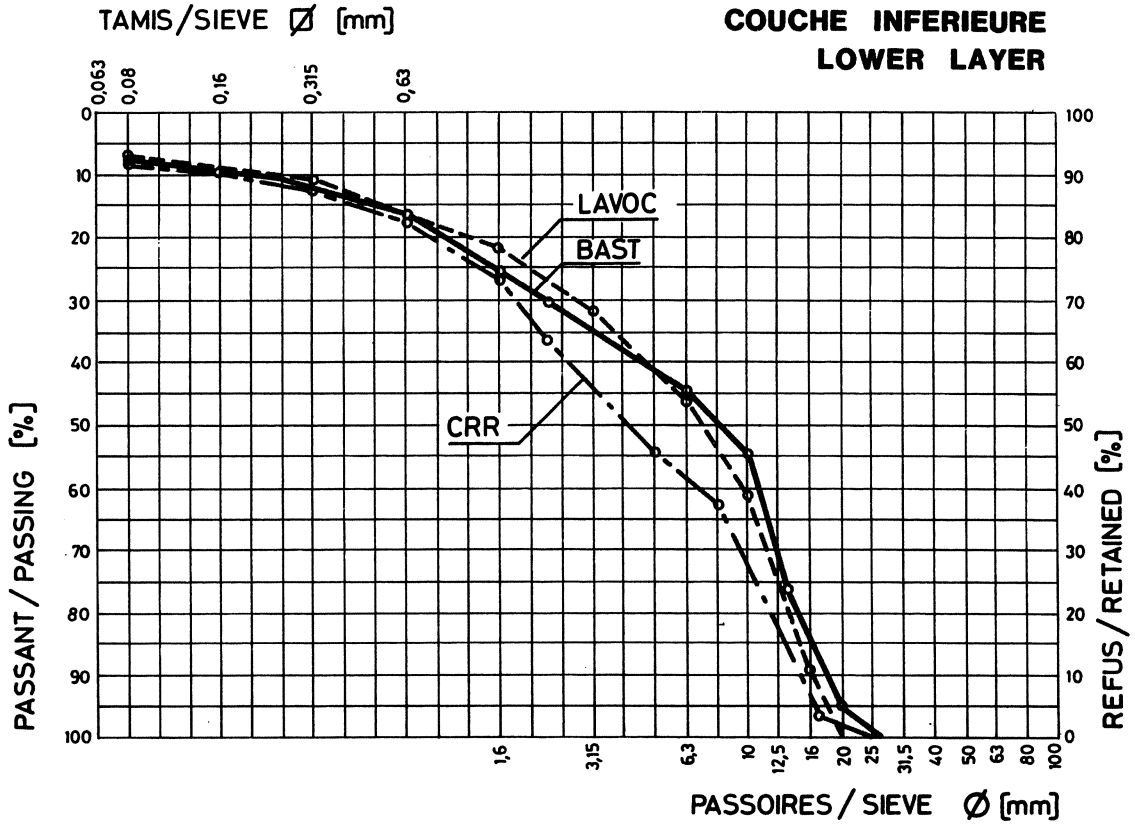


Figure IV.5: Grain size distribution of the lower layer

laboratory	CRR	BAST	LAVOC	Mean value
Temperature Ring and Ball [°C]				
upper layer	46.0	48.5	50.5	48
lower layer	48.0	49.0	49.5	49
Penetration at 25 °C [10^{-1}mm]				
upper layer	21	56	51	43
lower layer	45	55	43	48

Fig. IV.7 Binder properties

IV.3.3 Moduli

IV.3.3.1 Introduction

Two research laboratories, CRR and BAST, have determined the moduli of the bituminous material using three different methods. The results obtained in a very narrow range allow the understanding of the behaviour of those materials for different loading times and temperatures. CRR has also drawn conclusions concerning the fatigue properties of these bituminous materials.

IV.3.3.2 Moduli determined by CRR, Belgium

The determination of moduli and resistance to fatigue has been made on specimens cut from a slab extracted from the test pavements at Nardò, including material of the upper and lower bituminous layers.

Measurements have been carried out using the repeated flexion apparatus of the Centre de Recherches Routières (Brussels, Belgium) in co-operation with the CRR and the LAVOC laboratory in Lausanne, Switzerland.

For each layer moduli have been determined for sinusoidal flexural loading on trapezoidal-shaped specimens cast at their base. The following test conditions have been chosen:

- freqencies : 1, 3, 10, 30, 56, 91 Hz
- temperatures: -20, -5, 15, 30 °C

Figure IV.8 gives a synthesis of the results obtained: the graph indicates the master curves of the modulus $|E^*|$ at a reference temperature of 15 °C for the surface (upper) and binder (lower) layers.

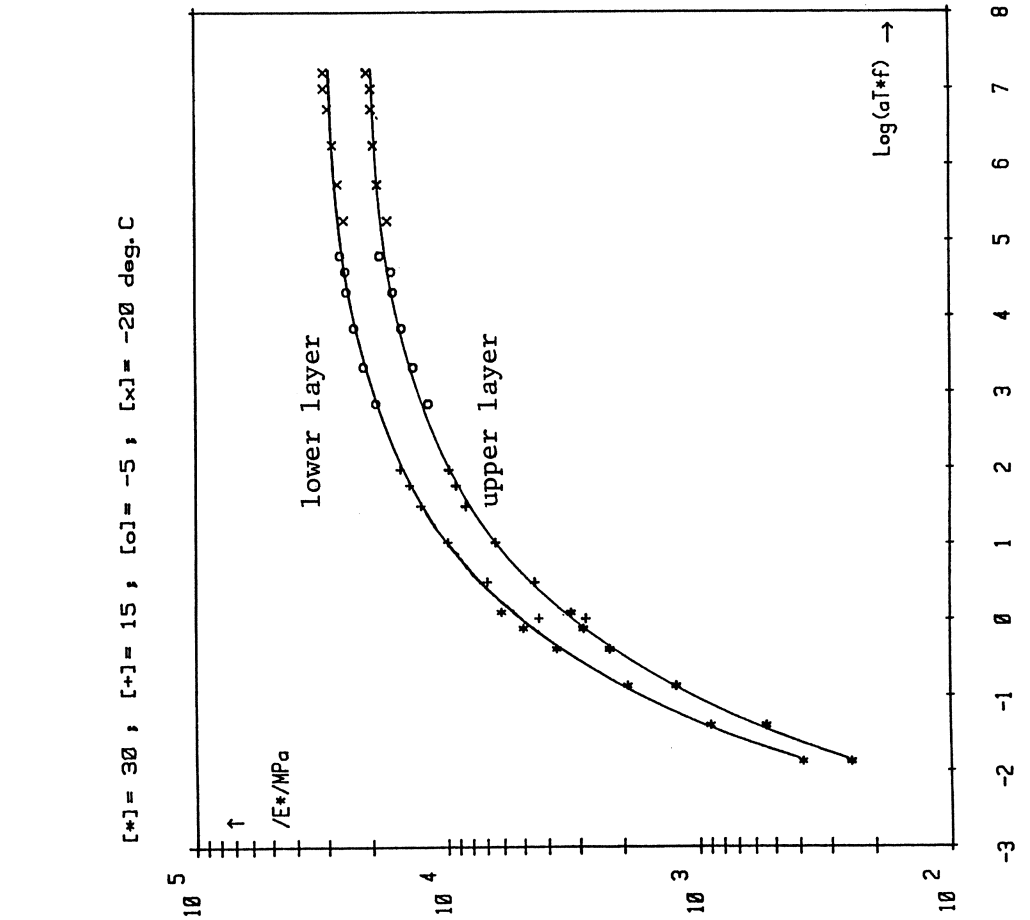


Fig. IV.8 Master-curves (temp. ref. 15 deg. C)

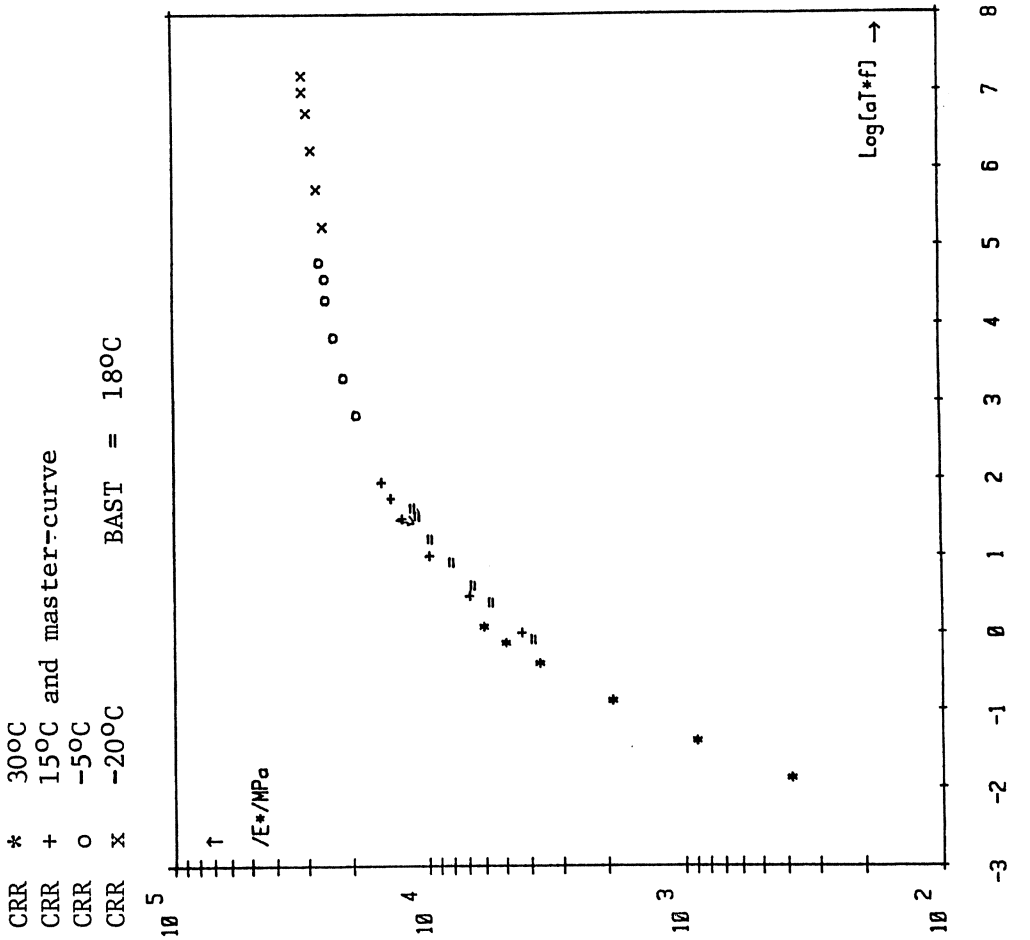


Fig. IV.9 Master-curve (temp. for the lower layer 15°C)

In the figure, the parameter α_T is given by the following experimental relationship:

$$\alpha_T = \exp\ 2.5179 \cdot 10^4\ \left(\frac{1}{T} - \frac{1}{T_S}\right)$$

Due to differences in their composition, the two layers also have different moduli: the modulus of the binder layer is 1.55 times greater than the modulus of the surface layer independently from temperature and frequency.

In Figure IV.9 are shown the master curve of the modulus of the binder layer for the reference temperature of 15 °C as well as the moduli (mean values) obtained by the BAST at Bergisch-Gladbach, Germany, on the basis of repeated compression tests. It is important to notice the excellent agreement of the results obtained by two different methods.
The same difference is also demonstrated by the fatigue laws

$$\varepsilon = k \cdot N^{-a}$$

where ε = strain loading to rupture of the bituminous material after N repetitions (Fig. IV.10). Laboratory values, however, do not reflect actual fatigue life expectancies for both layers. These laws have been obtained from flexural tests under sinusoidal loading, with controlled deformation, at a temperature of 10 °C and 25 Hz.

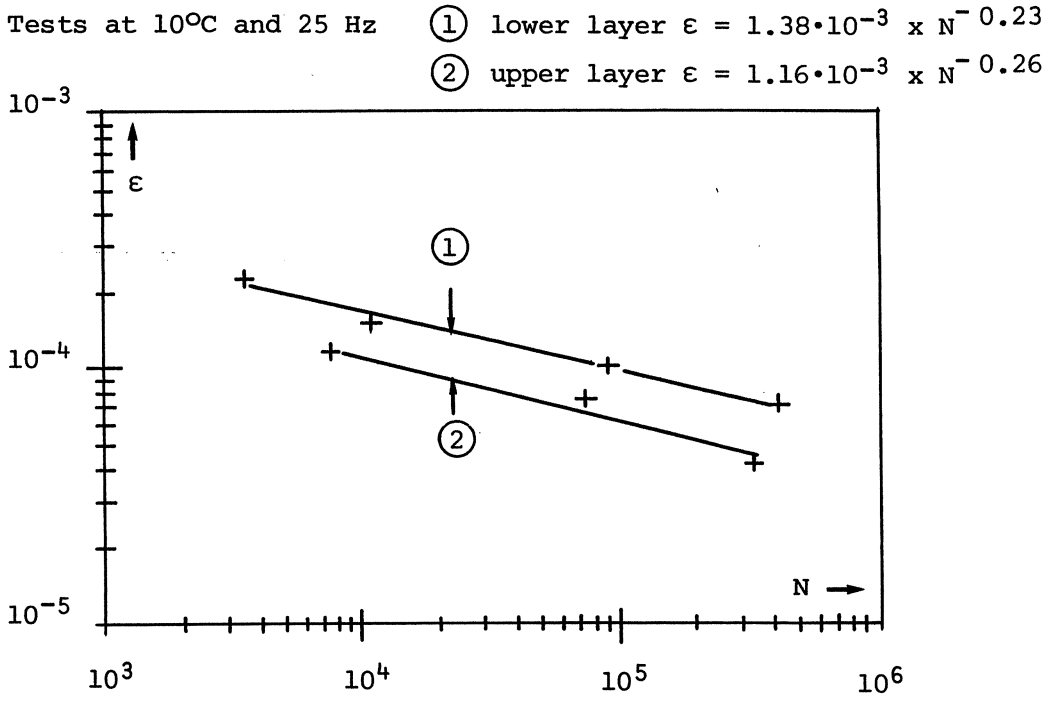


Fig. IV.10 Fatigue tests with repeated flexion under controlled deformation

IV.3.3.3 Moduli determined by BAST, Germany

- Introduction

When measuring the modulus of elasticity in the laboratory the samples were subjected to a certain load and the resulting deformation was measured. Taking into consideration a "form-factor" - representative for the type of loading and the form of the sample - the modulus of elasticity can be calculated from load and deformation. The following two types of loading were used at BAST:

1. When conducting the compression test, cylindrical samples were fixed on one side in a loading frame and the other side was subjected to sinusoidal loading. The longitudinal deformation - in this case for the lower layer only - was then measured by means of four LVDT's.

2. In the two-point-bending-test samples with a square cross-section (4 cm x 4 cm x 16 cm) are fixed with one side on the loading frame and the other side subjected to a perpendicular sinusoidal loading. The deflection is measured by means of one LVDT.

With both types of loading the sinusoidal load had a frequency ranging from 2 Hz to 120 Hz. Temperature were held constant within ± 0.2 °C; they can be varied in a range from - 20 °C up to + 40 °C. The samples of the two-point-bending-test are mounted in the loading frame in such a manner, that the direction of the test load corresponds to that within the pavement under the test wheel.

- Results

Four samples were removed from the cores No. 1, 3, 4, 6, 7, 8, 17 and 19, in order to get a number of values representative - if possible - for the whole section. As to the two-point-bending-test, three samples were tested within the temperature range from - 20 °C up to + 40 °C, two samples were tested from 0 °C to + 40 °C, and the others only at + 20 °C. As to the compression test, one sample was tested from 0 °C to + 40 °C, four samples at + 18 °C.

To begin with the bending test, the values of $|E|$ (absolute modulus of elasticity $|E| = \sqrt{E_R^2 + E_J^2}$) are given in Fig. IV.11 for a temperature of + 20 °C. Two diagram areas are to be distinguished, one for the upper, and one for the lower layer, which differ only slightly from each other. Two samples with relatively low values (4.22 u and 1.2 o) are not included in these areas. Taking as an example the $|E|$-values at a frequency of 8 Hz and a temperature of + 20 °C, referred to the respective mean values $|\bar{E}|$, the distribution of these values $|E|/|\bar{E}|$ for the lower layer, the upper one and for both layers is given in Fig. IV.12. The variation is wider for the upper layer than for the lower one. There obviously exists an upper limit for the absolute modulus, because the distributions in Fig. IV.12 are not symmetrical.

Both the frequency and the temperature dependency of $|E|$ are given in Fig. IV.13 for the sample 3.2 u as a representative example.

The temperature dependency of the modulus of elasticity can be seen in Fig. IV.14 based on a reference temperature of 20 °C (equal to 293 K) and on a frequency of 8 Hz. It is valid for both layers. The same can be stated for the compression test.

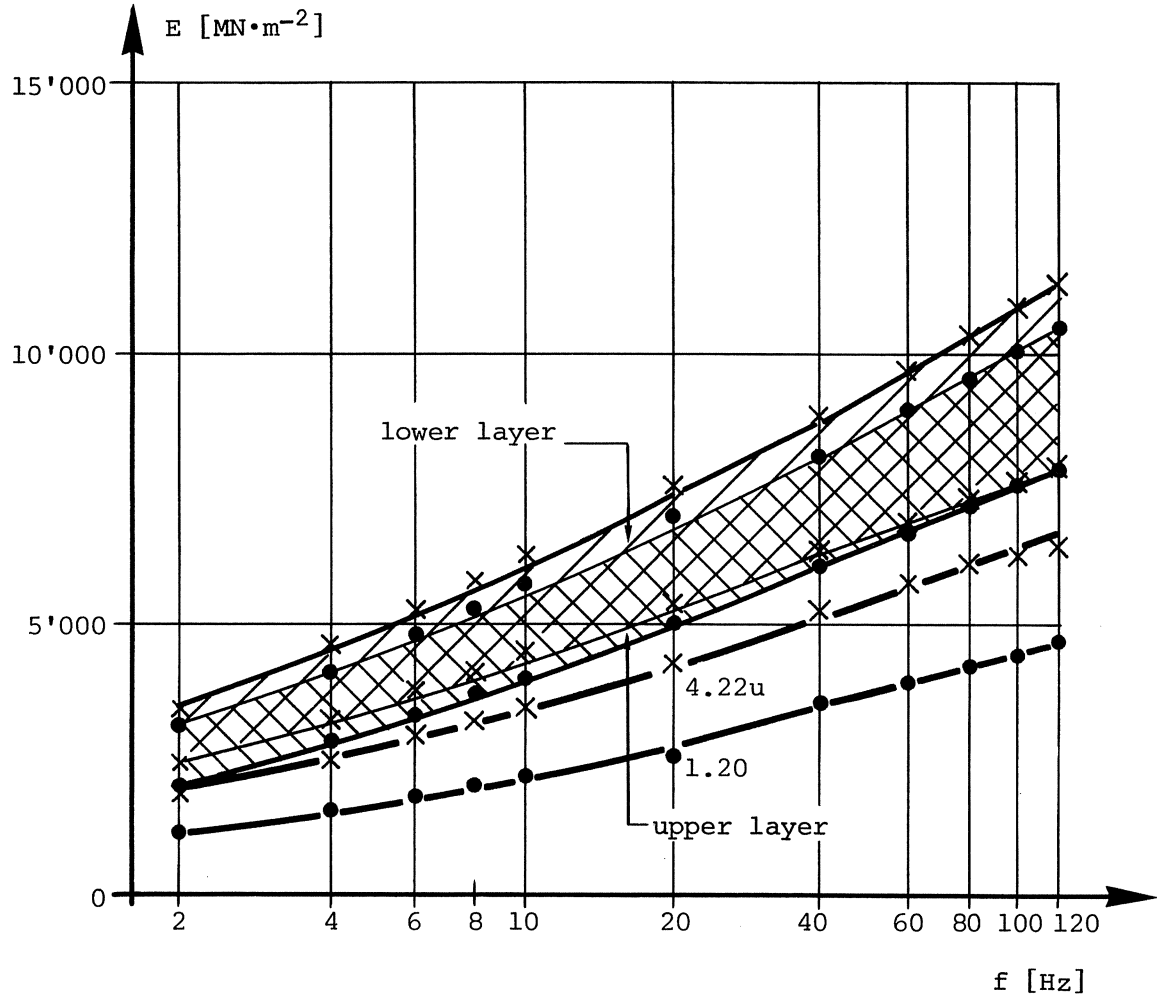


Fig. IV.11 The $|E|$-dependency of the test frequencies
(T = +20 °C - 293 K -; 25 samples two-point bending test)

IV.3.3.4 Conclusions

Of the results of the determination of the modulus of elasticity of the Nardô bituminous material, two are of special interest:

- the modulus of elasticity, which is to be applied for the calculation of strains under test vehicle loading using the corresponding calculation methods, and

- its variation with the temperature of the bituminous base course.

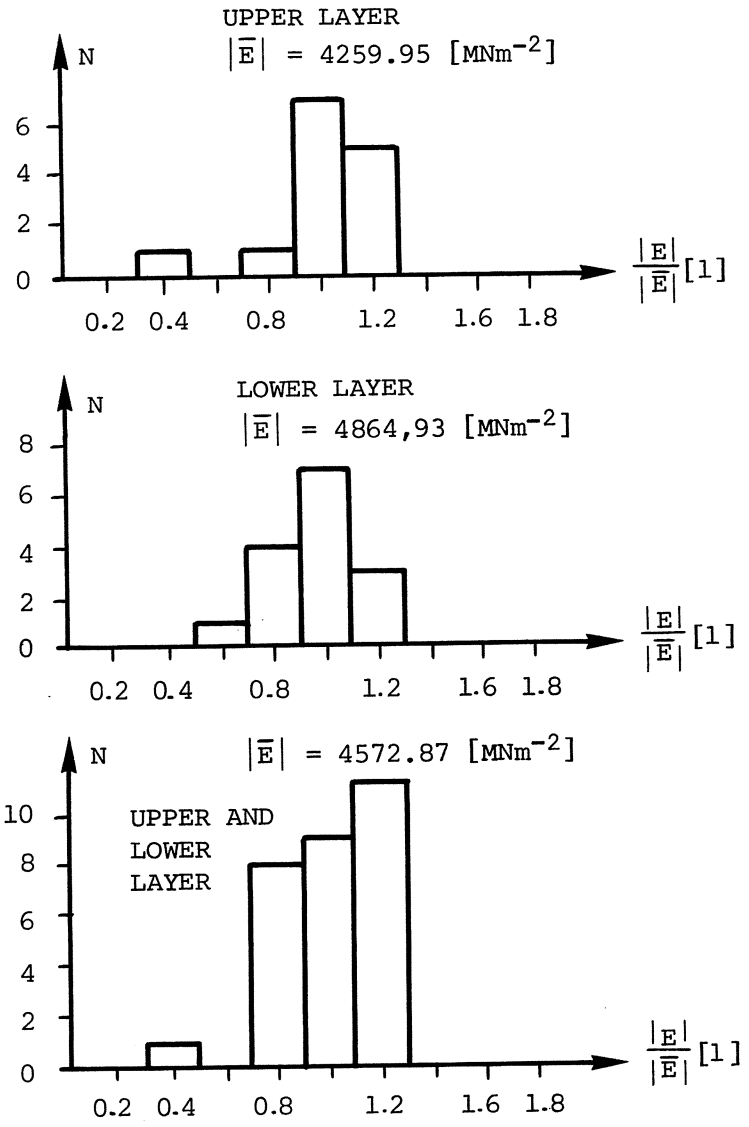


Figure IV.12 Distribution of the relative values of modulus

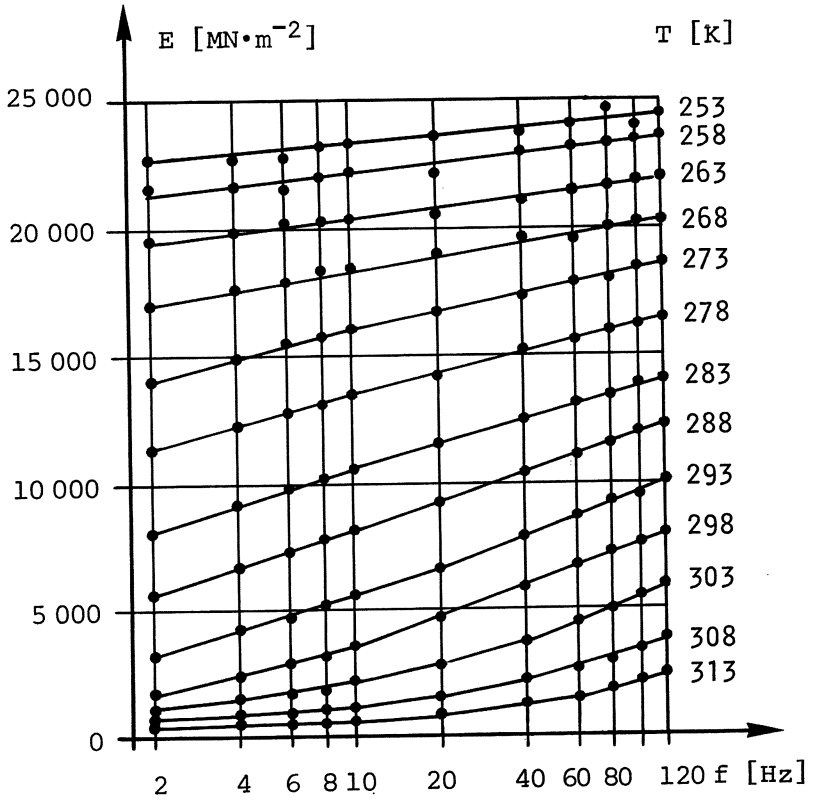
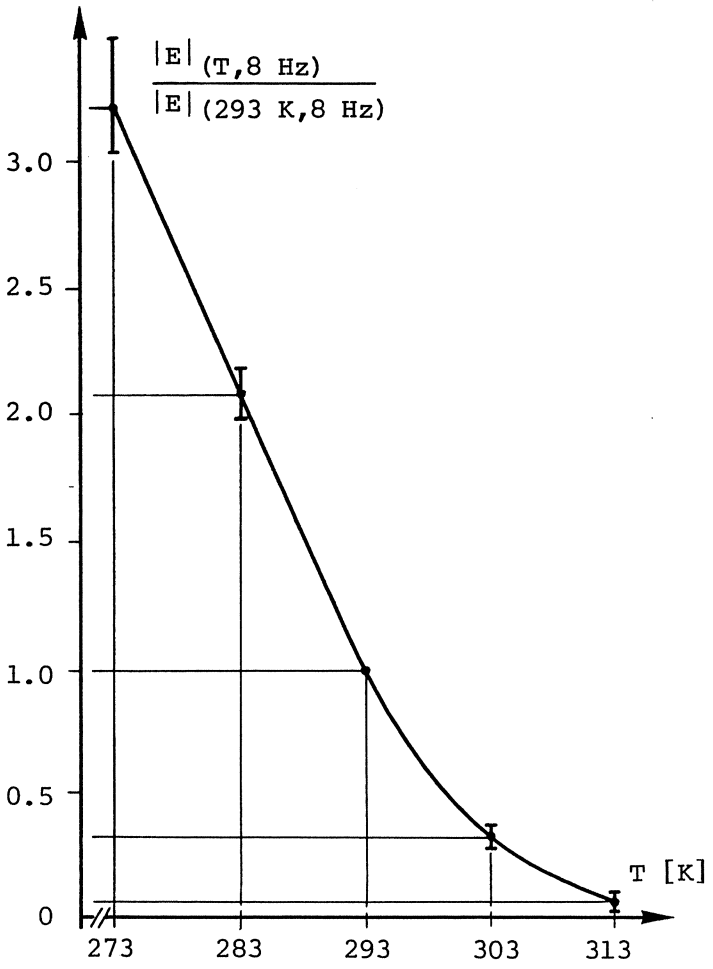


Figure IV.13: Frequency and temperature dependency (Example: sample 3.20 u)

Figure IV.14

Temperature dependency of $|E|$, related to a temperature of 20 °C (293 K) for both layers at a test frequency of 8 Hz

T [°C]	T [K]	$\frac{\lvert E\rvert_{(T,8\ Hz)}}{\lvert E\rvert_{(293\ K,8\ Hz)}}$
15.0	288.0	1.54
18.0	291.0	1.23
20.0	293.0	1.00
24.0	297.0	0.65
28.0	301.0	0.41
30.0	303.0	0.32
32.0	305.0	0.26
35.0	308.0	0.18



The temperature dependency of $|E|$ is given in Fig. IV.14 and, as described above, is valid for both layers, and changes only sligh with frequency.

As in the case of the moduli, also for fatigue resistance the influence of differences in the mixes of the two layers can be shown: for a given elongation the service life (number of cycles to failure) is about 10 times greater for the lower layer (binder) than for the upper layer (surface). This illustrates the important role of the void content on fatigue resistance and the necessity of suitable mix design and compaction.

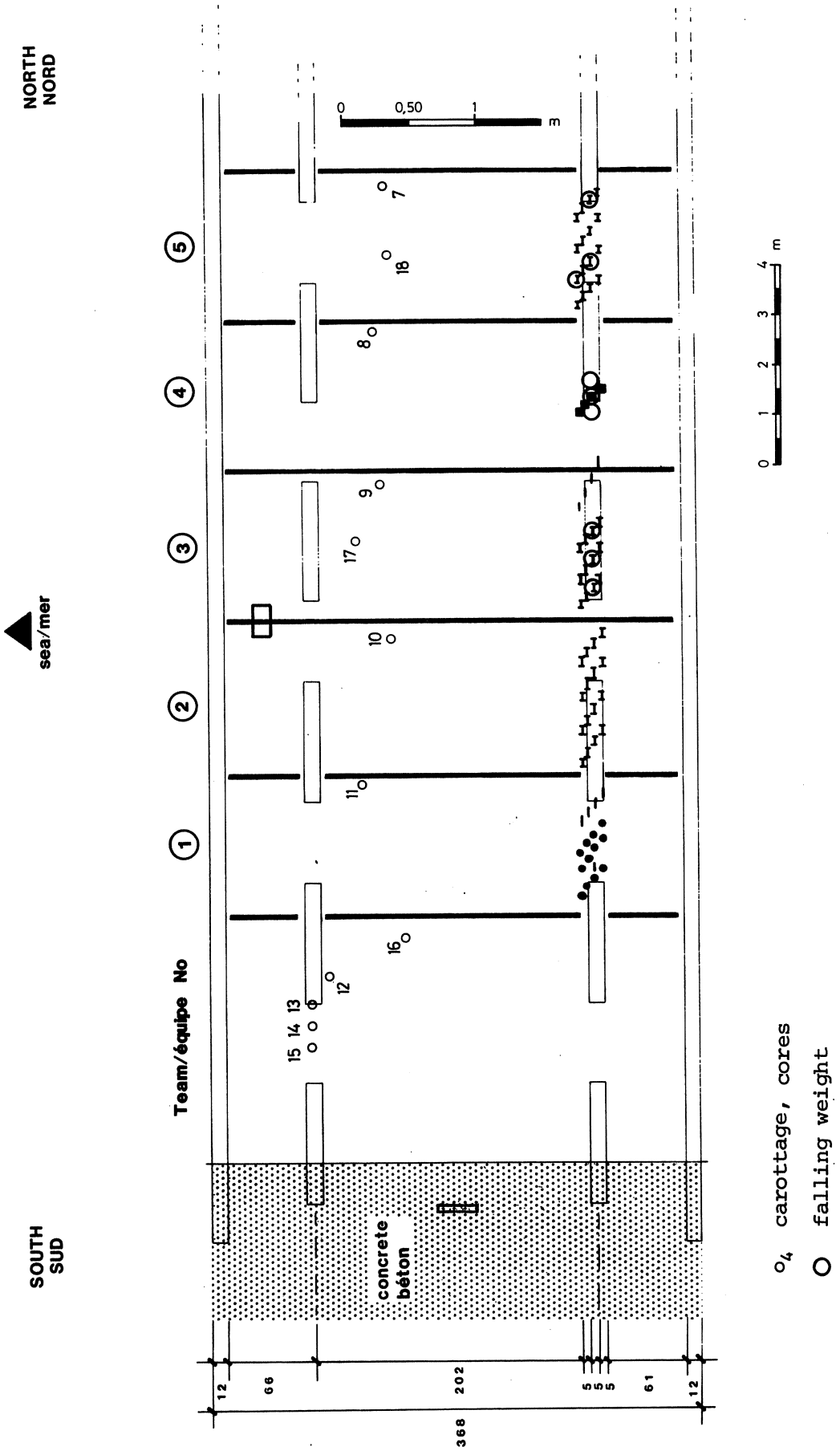
IV.4 CONTROL OF HOMOGENEITY

The dynamic loading tests carried out on the Nardò test pavement with two different devices, a Dynatest 8000 Falling Weight Deflectometer (FWD) and the Heavy Vibrator of BAST were intended primarily to check the homogeneity of the old portion of the pavement - the crushed stone base resting on the rock fill subrade - because Benkelman beam tests had not been possible on the crushed stone and the bituminous concrete. With appropriate analysis of the deflection basin, measured by both the systems used, the separate influence, and thus the moduli of many different layers can be calculated. As far as the moduli for bituminous concrete

Cores and "falling weight" layout

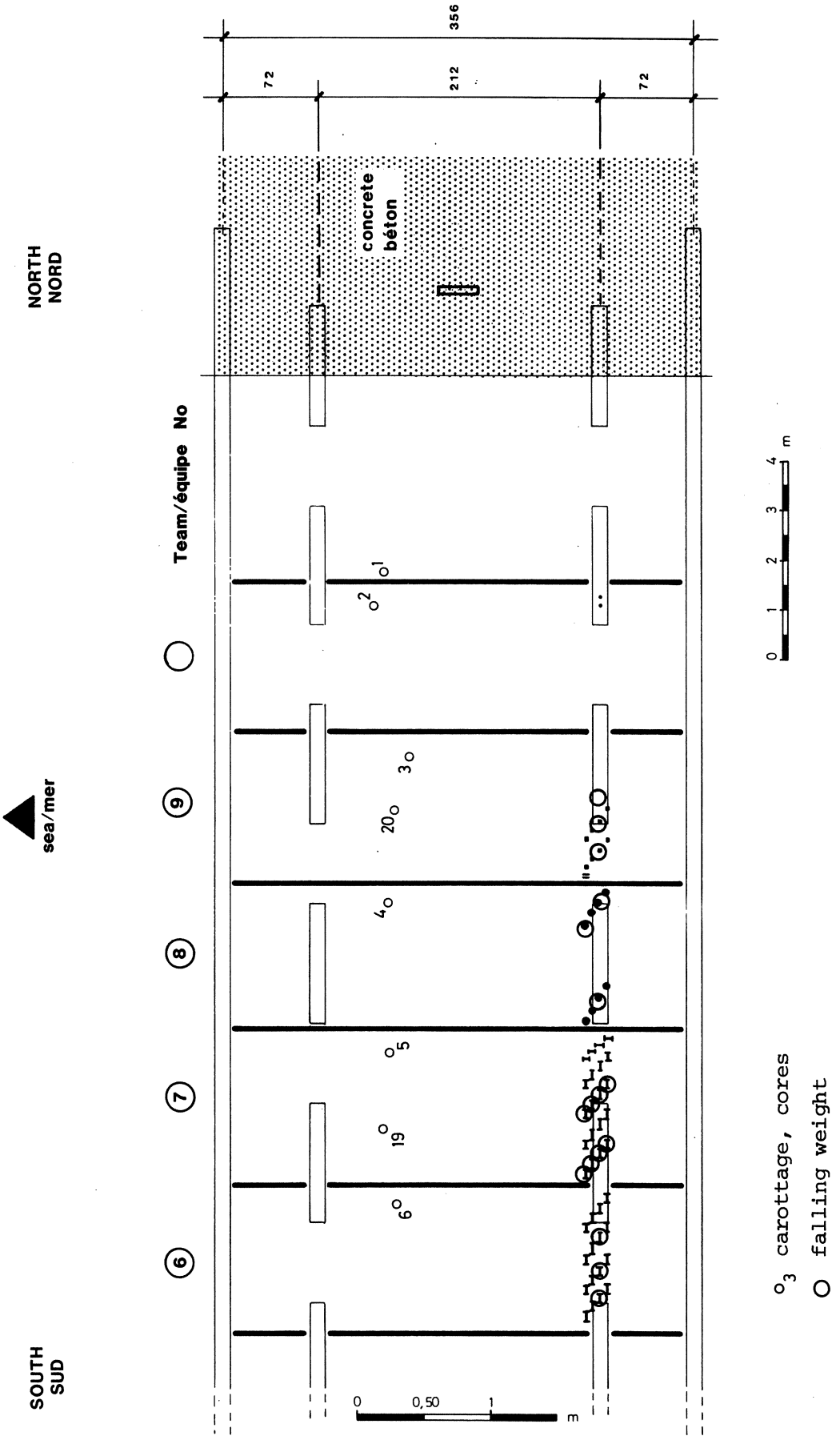
Plan de carottage et "falling weight"

Figure IV.15 a



Cores and "falling weight" layout
Plan de carottage et "falling weight"

Figure IV.15 b



Pavement temperature recorded by FWD operator: 23.2 °C

Team	Stress MPa	Deflections µm, at distance, mm, from center 0	300	450	600	900
1	0.716	364	190	112	65	23
2	0.725	344	180	110	64	23
3	0.707	352	192	120	73	24
4	0.714	379	214	128	74	22
5	0.712	389	217	134	79	25
6	0.702	409	230	145	88	25
7	0.711	355	209	131	81	25
8	0.702	376	209	134	86	31
9	0.708	389	227	143	91	34

Fig. IV.16 FWD-Testing data, April 11 (afternoon)

Pavement temperature recorded by FWD-operator: 15.5 °C

Team	Position	Stress MPa	Deflection, µm, at distance from center 0	300	450	600	900
	1	0.716	327	202	136	89	33
3	2	0.722	330	196	133	87	31
	3	0.735	305	197	134	88	33
	1	0.730	361	227	148	93	30
4	2	0.728	366	226	147	92	30
	3	0.725	364	219	142	88	26
	1	0.716	392	236	157	101	35
5	2	0.712	398	239	160	105	37
	3	0.714	403	243	162	105	35
	1	0.712	381	240	164	106	37
6	2	0.706	396	249	167	111	38
	3	0.709	379	237	162	106	38
	1	0.697	341	214	147	96	35
	2	0.701	336	212	144	95	35
	3	0.702	337	206	144	93	33
7	5	0.709	330	205	139	91	34
	6	0.709	350	208	140	91	33
	7	0.707	353	211	142	92	34
	8	0.707	355	211	141	92	35
	1	0.702	364	220	150	101	42
8	2	0.699	366	222	152	101	41
	3	0.713	313	203	140	92	38
	1	0.712	355	232	160	107	44
9	2	0.708	354	233	158	106	43
	3	0.710	357	222	151	102	41

Fig. IV.17 FWD-Testing data, April 12 (morning)

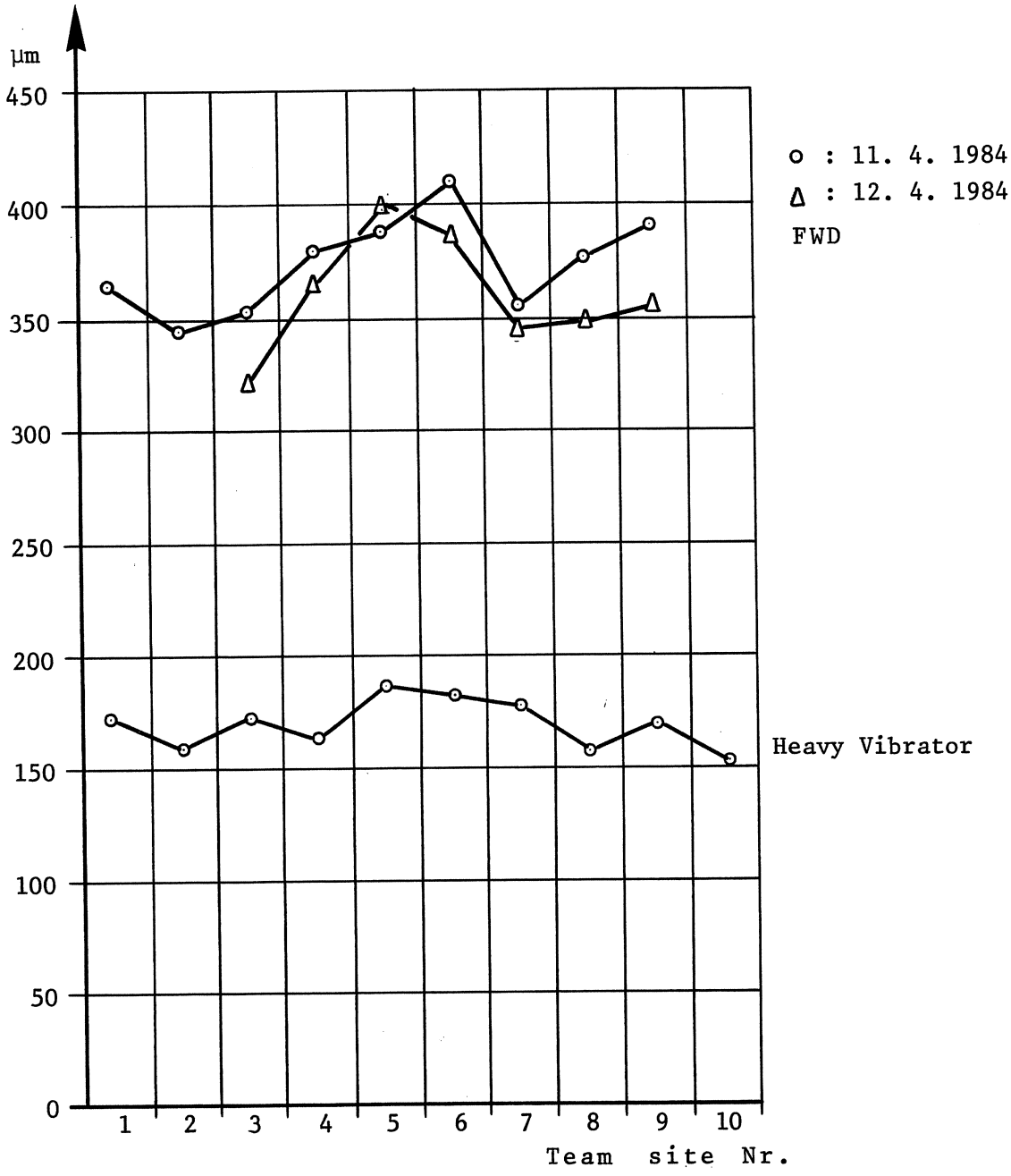


Fig. IV.18 Maximum deflections from dynamic loading tests (results from the BAST Heavy Vibrator extrapolated to a 50 kN load).

determined by dynamic loading tests are concerned, this information furnishes knowledge of the quality and homogeneity of the material in place as already indicated in sub-chapters IV.2 and IV.3.

IV.4.1 Falling Weight Deflectometer Tests

IV.4.1.1 Description of test and results

The AUTOSTRADE Company made their Falling Weight Deflectometer (FWD, Dynatest 8000) available for the experiment on the afternoon of April 11 and during the morning of April 12. All tests were carried out with a 300 mm diameter plate and most of the tests with a stress level (σ_o) of approximately 0.7 MPa, corresponding to a total load of approximately 50 kN or a little less than the load on a dual wheel of the rear axle of the trucks. Deflections were measured at the following distances from the center: 0 mm, 300 mm, 450 mm, 600 mm, 900 mm, 1 200 mm and 1 500 mm. Due to the stiff rock at some (unknown) depth the deflections measured at 1 200 mm and 1 500 mm from the center could not be used for calculation of the moduli of the pavement layers.

On the afternoon of April 11 one FWD test was carried out at the test site of each team (mean pavement temperature: 23.2 °C). On the morning of April 12 (mean pavement temperature: 15.5 °C) the FWD was available to all teams for testing. Normally 3 tests were carried out on each test site, but for team No. 7 eight tests were carried out, located at gauge positions 131, 121, 111, 101 (group 1) and 133, 123, 113 and 103 (group 3). Apparently, due to a misunderstanding, no tests were done at the sites of team No. 1 and team No. 2 on April 12. The approximate locations of the tests on April 12 are shown in Figure IV.15.

The results of the tests are given in figures IV.16, 17, 18. For each test three drops were made, but only the stress, in MPa, and the deflections, in μm, from the last drop are shown in the tables and only for distances out to 900 mm from the center of the loading plate.

IV.4.1.2 Calculation of moduli

Due to the shallow depth of the sondstone rock a special version of the ELMOD program was used for the calculation of moduli. This version first calculates the equivalent depth of the rock and considers the material below this depth as infinitely stiff.

For the materials above the sandstone rock a three-layer system was assumed. This consisted of bituminous surface (consisting in fact of 2 layers), granular base and subgrade. The combined thickness of the bituminous layers was measured on cores taken from the test field. From six cores taken from test sites 1 - 6 the mean thickness was found to be 130 mm, with a standard deviation of 2 - 6 mm, and from six cores from sites 7 - 9 the mean thickness was 136 mm with a standard deviation of 2.7 mm.

In calculating the moduli (and later also for calculating strains) a thickness of 120 mm of the bituminous layers has been used for sites 1 - 6 and of 135 mm for sites 7 - 10. For the granular base a thickness of 170 mm was used for all teams.

The results of the ELMOD calculation are shown in figures IV.19 and 20. E_1 is the modulus of the bituminous layers, E_2 of the granular base and E_3 of the subgrade, which in this case is a granular fill on top of the sandstone rock. All moduli are in MPa. The moduli are also shown in figure IV.21 as a function of the test position.

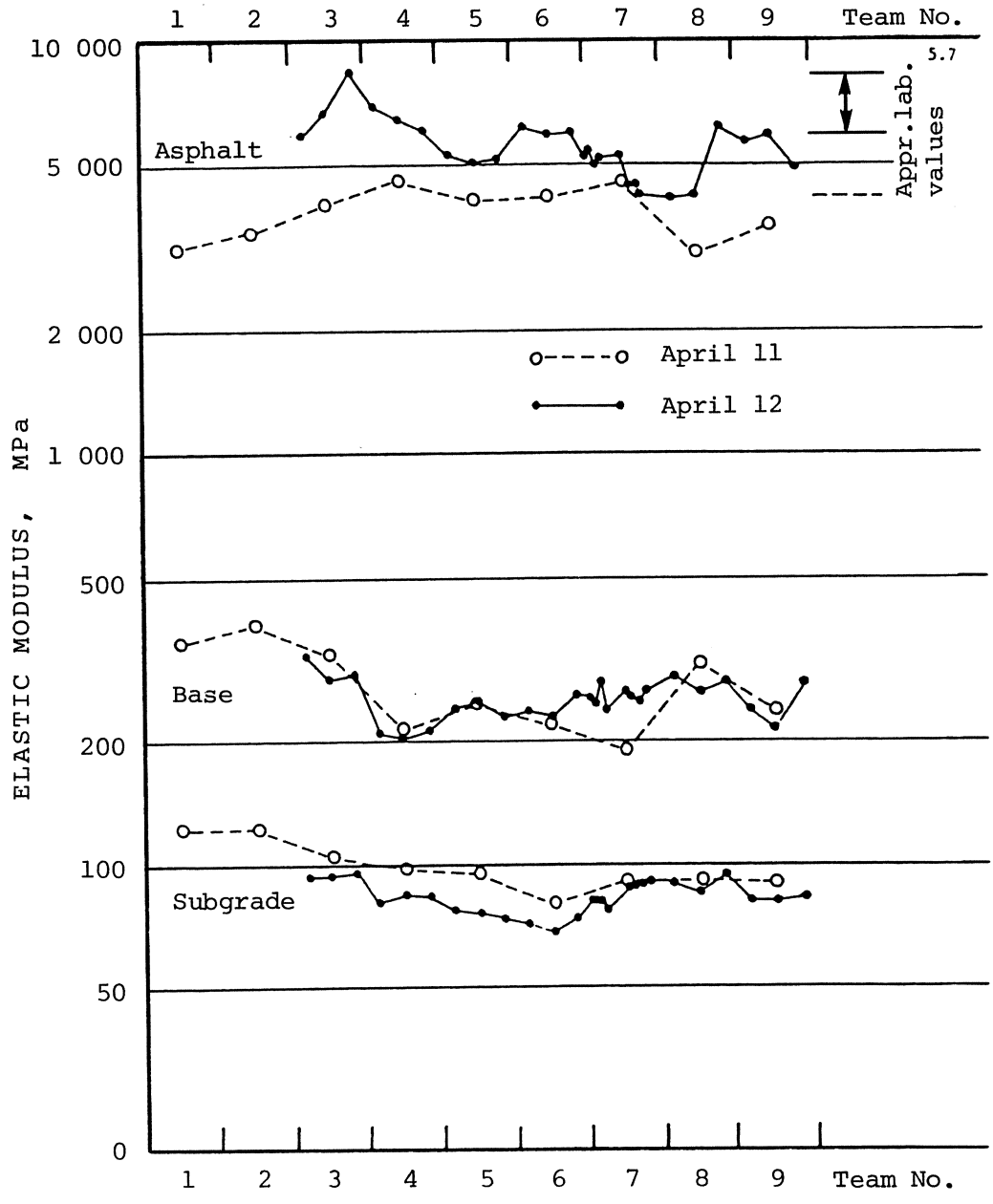


Figure IV.21 Elastic moduli from FWD-testing

Team	E_1, MPa	E_2, MPa	E_3, MPa	H_e, mm
1	3167	352	123	1239
2	3473	390	124	1219
3	4056	329	104	1192
4	4637	214	98	1141
5	4158	248	95	1171
6	4202	219	80	1123
7	4535	191	91	1159
8	3050	313	92	1253
9	3593	236	90	1283

Fig. IV.19 Moduli and equivalent depth calculated with ELMOD, April 11 (afternoon) (23.2 °C)

Team	Position	E_1, MPa	E_2, MPa	E_3, MPa	H_e, mm
3	1	5909	328	93	1244
	2	6751	286	93	1276
	3	8626	296	95	1286
4	1	6940	209	81	1181
	2	6470	203	84	1187
	3	6034	212	84	1139
5	1	5259	242	78	1225
	2	5053	251	76	1236
	3	5187	228	73	1200
6	1	6202	237	72	1230
	2	5898	231	68	1217
	3	5962	260	74	1249
7	1	5164	257	82	1286
	2	5422	247	82	1271
	3	4990	280	82	1241
	4	5136	237	78	1219
	5	5280	268	88	1283
	6	4436	255	89	1258
	7	4449	249	89	1273
	8	4230	266	91	1299
8	1	4152	287	89	1397
	2	4268	265	86	1367
	3	6333	282	94	1375
9	1	5716	236	81	1383
	2	5920	216	81	1366
	3	4749	280	84	1356

Fig. IV.20 Moduli and equivalent depth calculated with ELMOD, April 12 (morning) (15.5 °C)

The last column shows the equivalent depth to the sandstone rock (H_e) in mm. The equivalent depth is calculated as:

$$H_e = 0.8 \times H_{bit.mix} \times \sqrt[3]{E_1/E_3} + 0.8 \times H_{base} \times \sqrt[3]{E_2/E_3} + H_{subgrade}$$

The moduli of the bituminous layers may be compared to those obtained at BAST from compressive tests on cores. At 18 °C BAST determined values ranging from approximately 7 000 MPa to 9 500 MPa for a frequency of 20 Hz.

The BAST experiments were carried out on the lower bituminous layer only. Experiments at CRR showed that the modulus of the upper layer is 60 - 65 % of the value for the lower layer. Using 65 % and thickness of 50 mm and 80 mm for the upper and lower layers respectively, the composite moduli of the two layers becomes 5 970 MPa to 8 110 MPa. The FWD moduli range from 4 200 MPa to 8 600 MPa at approximately 15.5 °C.

At 23 °C BAST obtained a modulus of approximately 5 000 MPa, thus a composite modulus for both layers of about 4 270 MPa, where the FWD testing results in 3 900 MPa.

It is reasonable that the FWD tests result in somewhat lower values than the laboratory tests, because the FWD tests include any lack of compaction or adhesion at the interface between the two bituminous layers, which is not included in the laboratory tests.

IV.4.2 Measurements with the Heavy Vibrator

The Heavy Vibrator of BAST was used on the 9 team sectors of the Nardò test section to measure deflections in a way similar to the "Dynaflect"-method. The vibration frequency used was 8 Hz, kept constant within +/- 0.1 Hz. The load amplitude was 2 150 N. The dead weight of the vibrator is 20 000 N, the load is applied to the road surface by a loading plate with a radius of 15 cm.

The possible frequency deviation of ± 0.1 Hz results in an error in the force amplitude which can amount to ± 2.5 %, because the force varies with the square of the number of revolutions for the "unbalance type" vibrator.

Vertical deflection was measured on the plate, and at distance of 30 cm, 60 cm, 90 cm and 120 cm from the center of the plate by means of geophones.

The geophones had been calibrated at BAST for the measuring frequency of 8 Hz on a vibratory-type shaker together with the display unit. The maximum error in the deflection when measuring the deflection basin thus amounted to ± 3.5 %.

The vibrator was positioned on the eastern yellow line in the middle of each sector and the deflection basin measured in three directions, to the north, the west and the south.

The results given in Fig. IV.18 have undergone a linear extrapolation to a load of 50 kN, so as to be in the same order of magnitude as those measured with the FWD-System. In this particular case deflections measured by the heavy vibrator are noticeably lower than those determined with the FWD-equipment. It should, however, be kept in mind that the actual load used with the heavy vibrator is much lower and that the particular type of structure with fill material between the pavement and the underlying rock and the differences in the exact measurement location may have led to this correlation of both test methods which is somewhat poorer than usual.

Both test methods show, in any case, that the bearing capacity of the total pavement structure is not homogeneous.

Chapter V

TEST CONDITIONS

V.1 DEFINITIONS

The term of test conditions defines in the following chapter all the parameters with direct influence on the load passages, in particular
- the mass and the geometric characteristics of the load,
- the speed of each load passage,
- the transversal distribution of load passages,
- the temperatures of the air and the bituminous concrete during teh loading periods.

The three last parameters are of variable nature, so the measuring method and the collected data are presented. The effects of some of these variations are also discussed due to their importance on the results of the strain gauge measurements.

V.2 LOAD: MASS AND GEOMETRIC CHARACTERISTICS

For the loading tests three trucks provided by the direction of the track (SASN) for the OECD programme have been used. The trucks were market with the letters A, B and C and this lettering sequence also corresponds to the order of passage during the complete test programme. As indicated in chapter II, it should be remembered that truck traffic was in the south-north direction on monday, April 9 and wednesday, April 11 and in the north-south direction on tuesday, April 10.

Vehicles A and C were identical, while vehicle B had a narrower front track and a longer wheelbase. The geometrical characteristics of the three vehicles have been measured on site and are indicated in fig. V.3. The axle load (mass in kg) and the tyre pressures are indicated in the following figures V.1.

Truck		A	B	C
Mass, front axle	kg	5500	6000	5500
Mass, rear axle	kg	11600	12000	11600
Pressure,front tyres,	bar	7.25	8.00	7.25
Pressure, rear tyres,	bar	8.00	8.00	8.00

Figure V.1 Mass and tyre pressure of the test vehicles

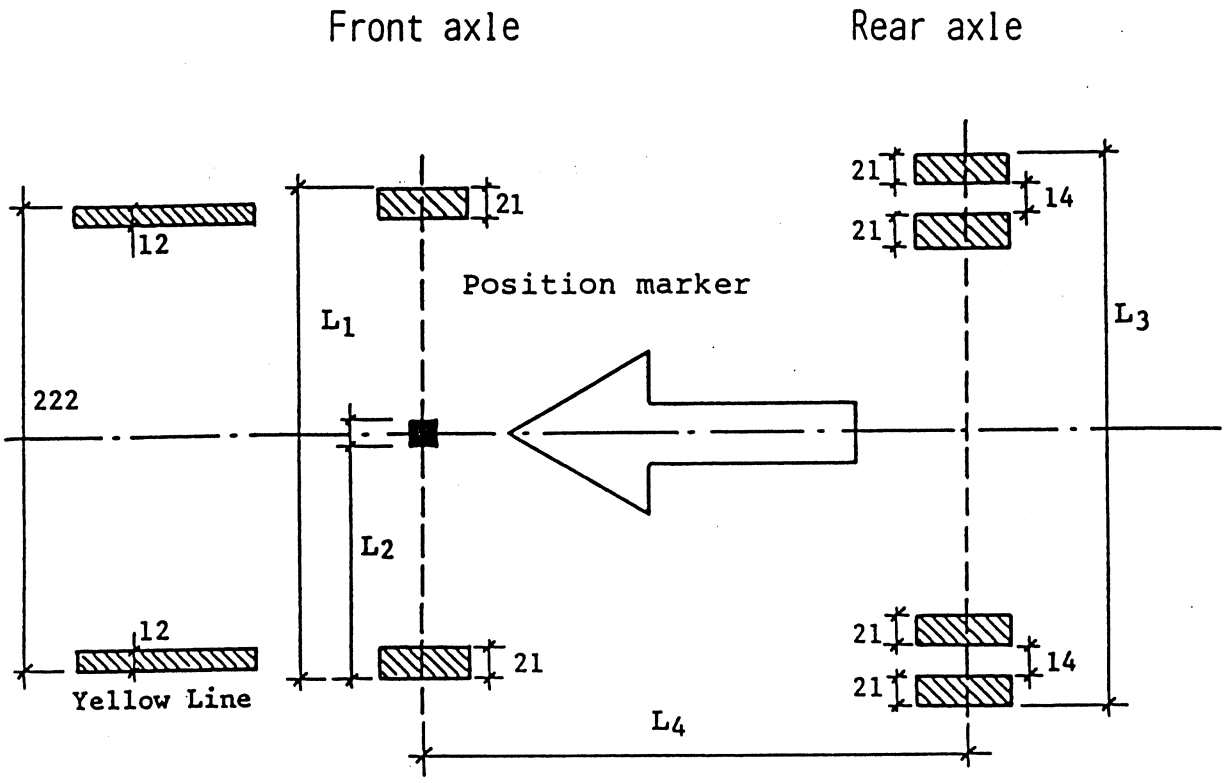
V.3 TRUCK SPEED

A loading vehicle speed of 30 km/h had been planned for the test programme. The E-Modulus of bituminous bound layers changes with the speed of loading as well as the strains measured under the load of the vehicles, e.g., at the subsurface of the bituminous bound base. For the comparison of the strains measured by the various measuring teams which in part employed different methods of measuring, a knowledge of the driving speed is not directly required. However, if the scatter of the test results is taken into account, the variations of the speed of loading vehicles also are important. For this reason the speeds of the three loading vehicles A, B and C were also measured during each passage.

This was carried out by means of two light barriers, spaced 10 m apart and placed at the end of the test section (comprising in particular the sites of the teams no. 8 and 9). However, it was not ascertained whether the speed measured could be considered as applying to the test section as a whole. But it can be assumed that the variations measured within the sectors mentioned are representative of the section as a whole. The measuring equipment shown in Fig. V.4 allows the determination of a speed of about 30 km/h with an accuracy of ± 0.25 km/h. The mean values and variations for all vehicles and passages are given in Figure V.2 and all single speed values are given in annex B.1. Fig. V.5 shows the speed distribution for each vehicle an all passages.

Vehicle	A	A	B	C
Mean	[km/h]	31.6	32.3	30.6
Standard deviation	[km/h]	1.7	1.7	1.8
Coefficient of Variation	[%]	5.4	5.2	6.0
Number of values	[%]	77	80	85

Figure V.2 Statistical values for all passages



[cm]	Truck/ Camion A	Truck/ Camion B	Truck/ Camion C
L 1	230	209	230
L 2	112 - 120	112 - 119	110 - 118
L 3	239	242	239
L 4	345	380	345

Figure V.3 Positions of the truck-wheels

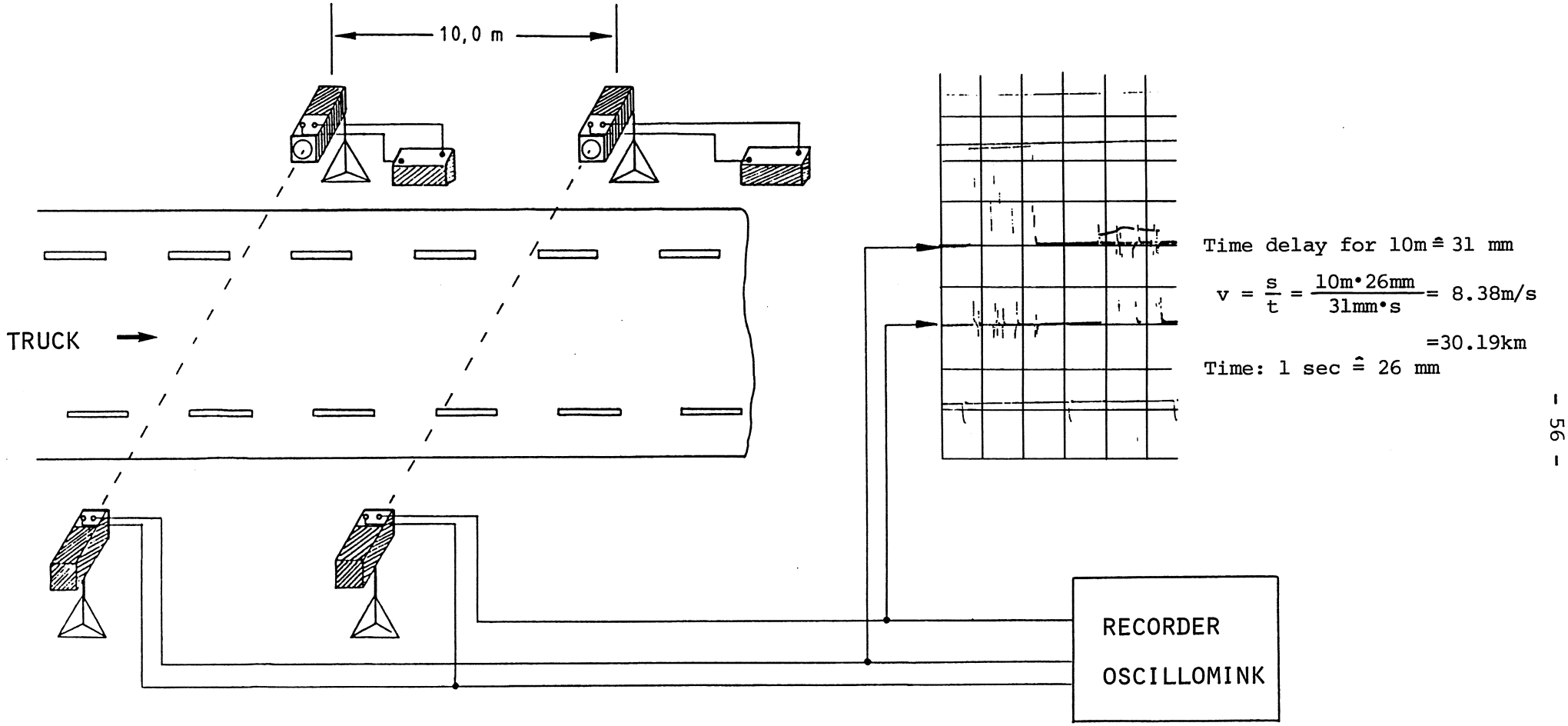


Figure V.4 Scheme of truck-speed measuring equipment

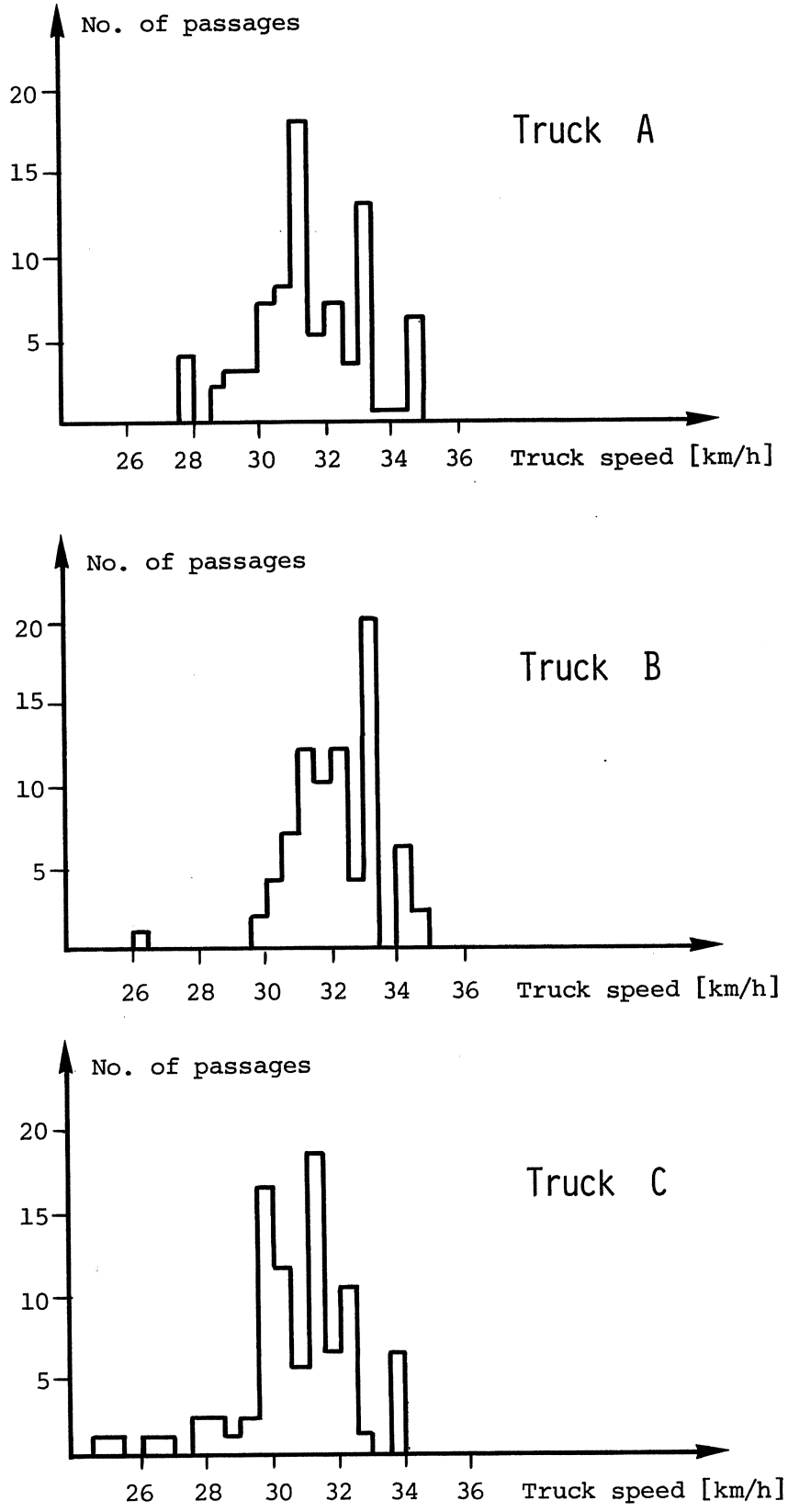


Figure V.5 Class frequencies of truck speed (all passages)

V.4 TRANSVERSE DISTRIBUTION OF LOAD PASSAGES

The transversal position of the vehicles has been measured at both ends of the test section (south = in front of the site of team no. 1; north = behind the site of team no. 9). The measurement was done using a system with a magnetic contact placed at the center of the pavement. The contact was activated by a metal strip fixed more or less at the centre of the front axle of each vehicle. The system allows the control of the transversal distribution in a range of ± 200 mm with a resolution of 25 mm.

As a function of the geometrical characteristics of the vehicles and of the position of the metal strip on the front axle (see Fig. V.2) each "central" passage, i.e. a load passage with a 0 difference between the strip and the centerline of the pavement, gives the "coverage" indicated in Fig. V.6 on the fixation lines of the strain gauges. Considering these two theoretically ideal positions, one should expect to find maximum strain values for the rear axles towards the outer edge of the pavement cross-section (lines 0 and 1).

On the basis of the positions recorded for each passage of all the vehicles at both ends of the test section six histograms of transverse distribution of wheel passages in the instrumented area have been developed (Fig. V.7). The histograms give the number of cumulated passages of tyres in width subdivisions of 25 mm (width of 1 tyre = 8 subdivisions = 200 mm).

As already suggested by the theoretical position, the distribution of the rear wheel (for which the comparison of strain measurements is made) is somewhat eccentric towards the outside.

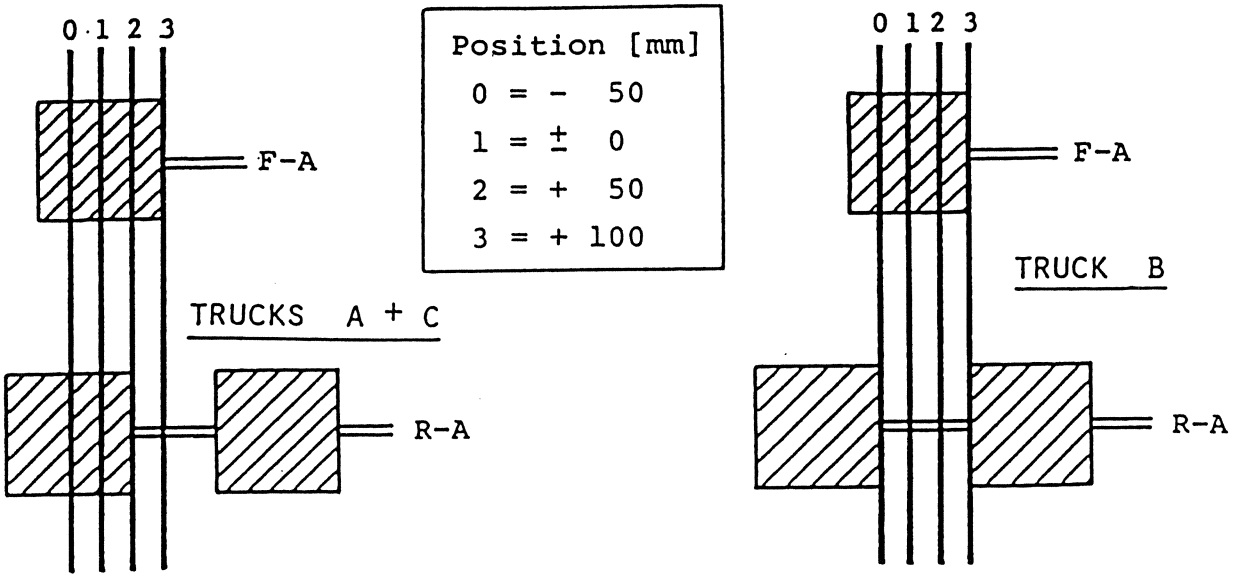


Fig. V.6 Theoretical "coverage" of the strain gauge positions

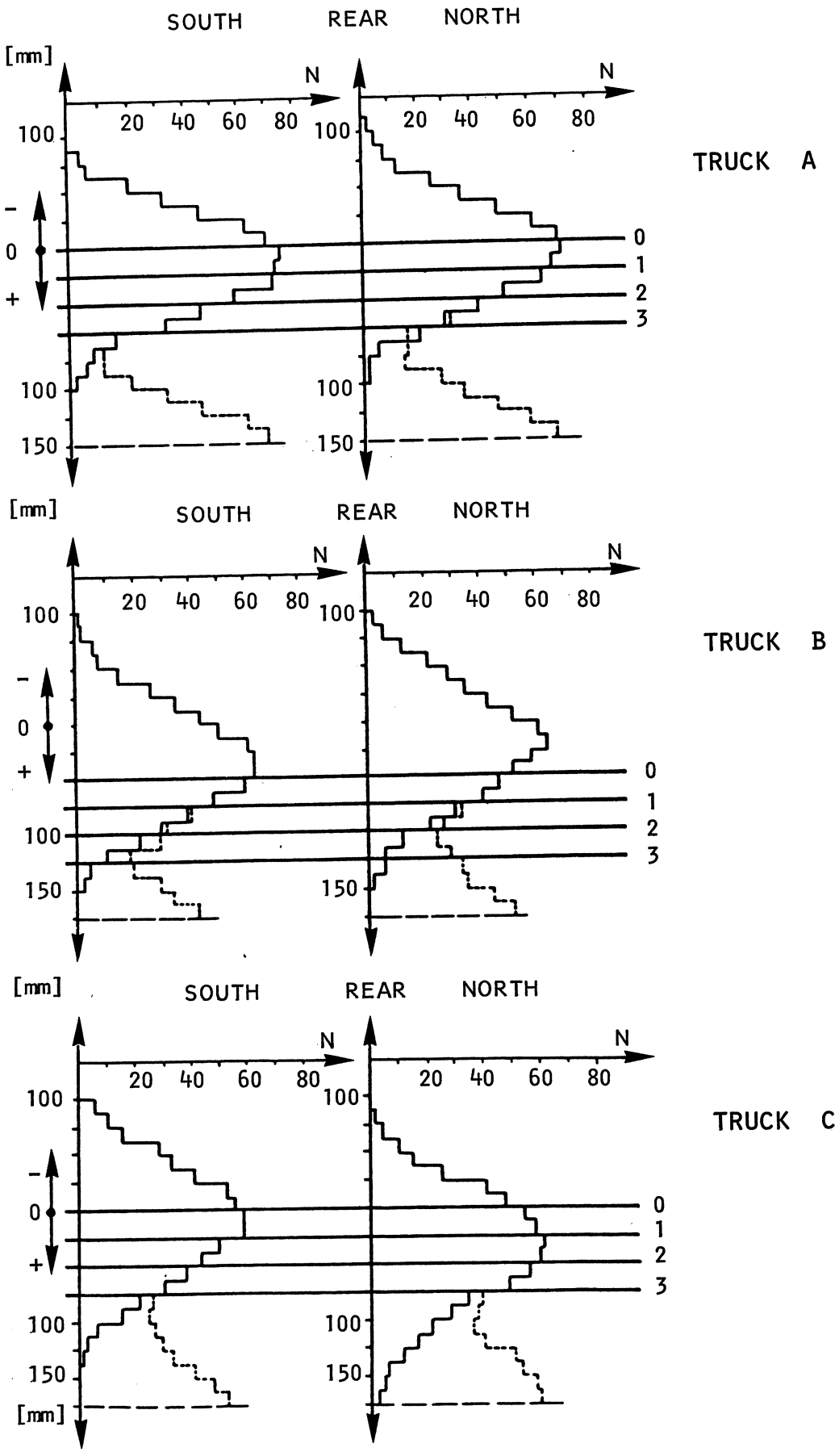


Figure V.7 Histograms of accumulated passages for the rear axle

V.5 TEMPERATURES

Temperatures in the bituminous layers have been measured by teams no. 1, 3 and 9 on their pavement sites. Each team used the method and equipment it normally uses, in particular:

a) Team no. 1

Thermocouples have been placed at nominal depths of -13 and -5 cm in a cut made into the bituminous layers from the edge of the pavement and refilled with bituminous mix. The sensors were conected with a 4 channel recorder preprogrammed for digital output of results.

b) Team no. 3

Pt-100 type resistance thermometers are protected by a 6 cm long steel tube, filled with silicone. The connection between the 3 core cables and the protective tube is sealed with a thermo-resisting rubber tube. All the measurement locations (-13 cm; -5 cm; surface; shaded position) were equipped with two sensors each. A 40 channel recorder was used only at 10 % of its capacity (4 channels). Temperature values of 4 sensors were recorded on paper every 15 minutes.

c) Team no. 9

Ni-100 resistance thermometers with teflon-insulated cables. The Ni-100 sensors are protected by a copper tube filled with a special glue (HBM x 60).

Two sensors each were placed on the surface of the granular base, between the two bituminous layers and in a shaded place for the measurement of air temperature. The additional sensor was also placed as near as possible to the pavement surface.

Team no. 9 also presented an additional method of measurement particularly suited for instrumentation after construction of the pavements. A core size specimen prepared in the laboratory and containing 4 thermometers is placed into a bore hole. The remaining space between hole and core is filled with a mix of bitumen and filler.

The transversal position of the temperature gauges of teams no. 3 and no. 9 corresponds to the yellow line on the pavement, while the sensors of team no. 1 were placed very near to the edge of the bituminous layers.

All the results of temperature measurements are included in annexes B.2 and B.3 and also partially in graphical presentation (Fig. V.8).

The analysis of these results shows some important differences between the temperatures as measured by the three teams (up to 10 °C between team no. 1 and no. 3). These differences were already discovered during the Nardò tests, so that comparative tests between the different systems were carried out. In the same water pot the three systems indicated values only 0.7 °C apart; the systems therefore, can be considered sufficiently accurate. Some additional control measurements with the sensors of team no. 3 and no. 9 made in 5 cm deep holes on both corresponding test sites of the teams showed a very good agreement between the two systems. They also showed the existence of a temperature difference of 3 °C between the two sites at that particular moment.

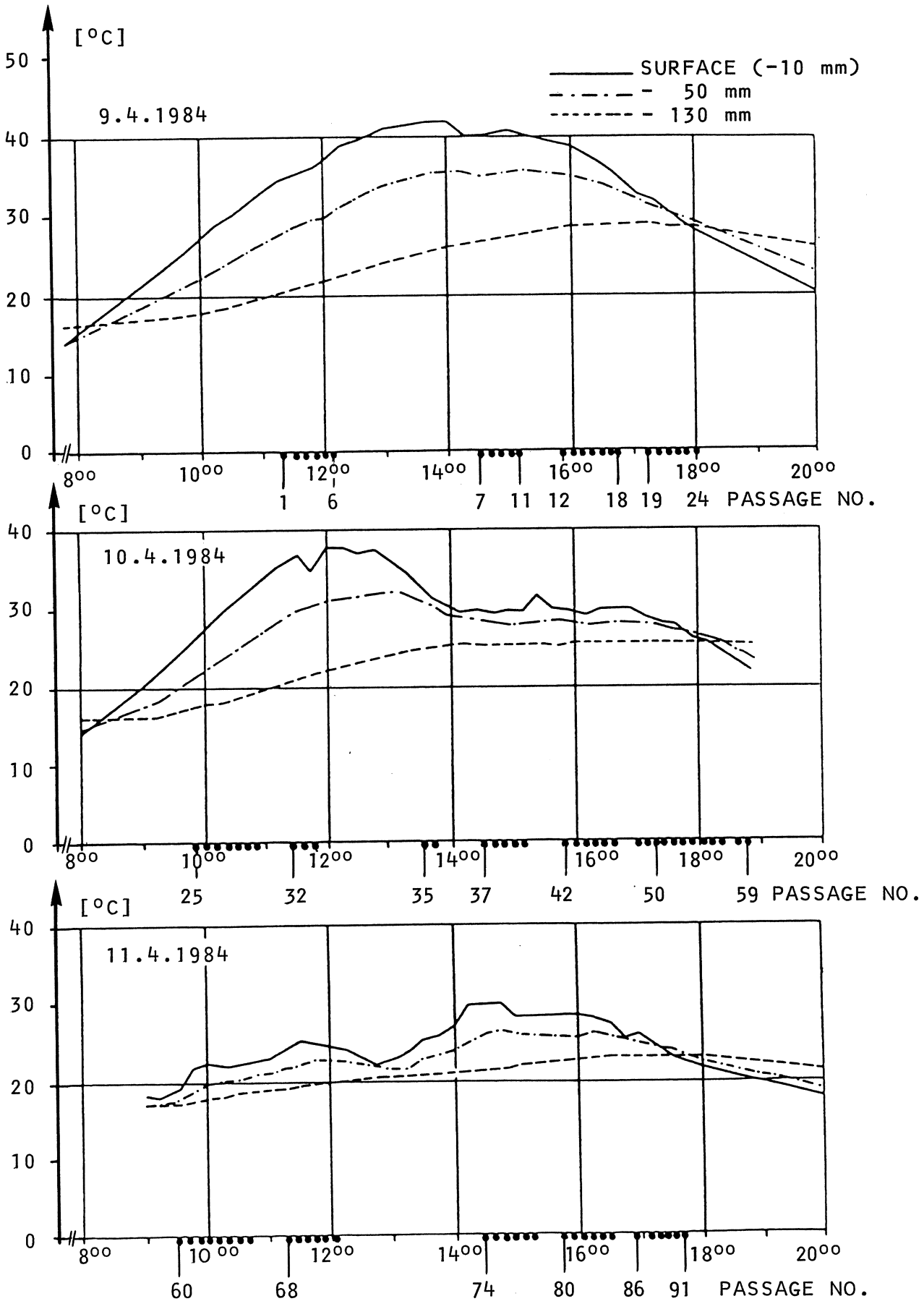


Figure V.8 Measurement of temperature - Team no. 3

Different factors can be the cause of such a difference and also of the differences registered with various measuring systems.

As it has been shown in chapter IV.2 that some important variations also concerned the thickness of the bituminous layers. Thus temperature gauges placed at the bottom of a layer are not necessarily at the same depth. The 12 mm in total thickness difference between the sites of teams no. 3 and no. 9 are in fact responsible for a major part of the temperature differences at the two sites.

The density of the bituminous material also can have an influence on the measured temperature values, as the thermal conductivity is dependent among other factors also on density. The values indicated for team no. 9 on the temperature gauges embedded in cores prepared in the laboratory (with a higher density than the test pavement materials almost always show, in fact, higher temperature values. From the point of view of material density and temperature distribution the results given by team no. 1, with the gauges just inserted into the bituminous material from the edge of the pavement, are also questionable.

Different wind exposure could in certain cases also lead to temperature differences. Wind conditions during the tests also varied with time and therefore they could not be held responsible for certain regular differences.

Chapter VI

RESULTS OF THE MEASUREMENTS

As described in Chapter III of this report, each participating country installed strain gauges in the pavement structure in the manner shown in Fig. III.14 and III.15 of Chapter III.

In addition to the measurements of strain carried out during trafficking, other significant variables were also monitored; these were the pavement temperature (measured at several depths by teams no. 1, 3 and 9), vehicle speed and transverse position of the vehicles during trafficking of the test sections.

The techniques used in these measurements are described in Chapter V, and the results are given in the Annex to this report, together with the measurements of strain recorded by the participating teams.

VI.1 ANALYSIS OF THE RESULTS

The purpose of the tests was to compare the instruments and techniques used by different countries to measure horizontal strains generated in a pavement by the passage of a loaded axle. Because of the variation of the measured strains with transverse vehicle position and pavement temperature (which is itself also variable with time and position along the test length), and also because of the inhomogeneities (Chapter IV) over the length of the experimental pavement, a first phase of analysis was conducted in which an attempt was made to illustrate the complications introduced by these variables. The results of this analysis were presented graphically, in order to see differences and variations more readily. Three different treatments of the results are described in detail in paragraphs VI.1.1 to VI.1.3 below. A comparison of pavement temperatures measured by each of three teams has been undertaken and is described in paragraph VI.1.4 below.

VI.1.1 Variation of measured strain with passage number

For each team, and for each of up to 4 groups of gauges, the variation of strain as a function of the number of passages has been determined. Each passage consists of individual passes of three trucks A, B, and C. Only the rear axles of the trucks were considered (in order to minimise variation due to the transverse position of the trucks), so that for a given group of up to 4 gauges there were up to 12 measurements of strain per passage. On the figures of annex B4 to B17, each of these measurements of strain is plotted for each passage number, together with the mean value of the measurements. The number of gauges operating at any given time is also noted on the graphs.

The tests were completed over a period of three days; the figures in annex B therefore indicate the variation of measured strain occurring through the day, which is partly a function of pavement temperature and is dealt with later in this analysis. Although the graphs take no account of the transverse position of the vehicles during each of the 91 passages, the range of results for each group of gauges is likely to be comparable between the different groups operated by each country because of the length of road they occupy. However, there is less likelihood of good comparability between the groups of different countries widely separated on the test site.

VI.1.2 Variation of maximum recorded strain with pavement temperature

In attempt to include the effect of pavement temperature as a variable and to minimise the effects of transverse position of the vehicle, a second treatment has been applied to the results as follows.

Each group of gauges is dispersed transversely about the trafficking line and therefore the maximum strain recorded by the gauge group, irrespective of where that gauge lies in relation to the trafficking line probably represents the strain directly or almost directly beneath the wheel.

Measurements of pavement temperature are available for each passage of a vehicle. It is possible therefore to transpose passage numbers to some characteristic pavement temperature, T. For the present purposes T has been defined as follows.:

$$T = [2T(-13) + T(-5)]/3$$

where T(-13), and T(-5) are the temperatures measured at 13 and 5 cm. depths respectively by team no. 3. A table of calculated values of T, together with the actual temperatures measured throughout the test period is given in Annexes B 2 and B 3.

The mean of the maximum strains recorded by each of the vehicles A, B and C was therefore plotted against the characteristic temperature for that passage number.

Generally, the relationship between strain in a bituminous pavement and pavement temperature is not linear. However, for calculations in a short range of temperatures it can be assumed as linear. For practical

reasons a linear regression was performed on the plotted data of each group of gauges for each country to give the regression coefficients and correlation coefficient shown on each of the Figures VI.2 to VI.10.

VI.1.3 Variation of strain at constant temperature

For the final part of this first phase of the analysis of strain measurements, it was decided to exclude, if possible, the variation of measured strain with pavement temperature, and to observe the effect of possible variations in the transverse position of vehicles passing over the test sections.

A study of the measured temperatures shows that while for passage numbers (3, 4), (17, 18, 19), (32 and 33) the temperature levels are different, the variation in temperature for groups of passages is very small; for these passages therefore the absolute maximum strain recorded by truck A, B or C, as well as the mean of the maximum strains recorded by each truck was plotted against the longitudinal position of the gauge, country by country, along the test site. Figure VI.11 shows the range of maxima thus measured, and differentiates between the three groups of passages (3, 4), (17, 18, 19), and (32, 33).

VI.1.4 Correlation between measured temperatures

Finally, because measurements of temperature were made by three teams, no. 1, 3 and 9 at points along the test road separated by up to 40 m, a comparison between these observations was undertaken.

As has already been stated, the characteristic pavement temperature, T, was taken to be a function of the measurements made by team no. 3. Two other functions were therefore defined:

$$T(a) = [2T(-13a) + T(-5a)]/3$$

where T(-13a) and T(-5a) are respectively the temperatures measured at 13 cm and 5 cm depth by team no. 9 and

$$T(b) = [2T(-13b) + T(-5b)]/3$$

where T(-13b) and T(-5b) are respectively the temperatures measured at 13 cm and 5 cm depth by team no. 1.

Figure VI.12 shows T(a) and T(b) plotted as functions of T, together with the appropriate linear regression coefficients for each of the correlations.

VI.1.5 Remarks on the first phase of analysis

The analyses presented so far have used the measured data to identify differences in measured strain levels between the various groups of gauges employed by a single team or the variation of strain with pavement temperature for any group of gauges.

The wide dispersion of measured data collected under nominally identical conditions of temperature, vehicle speed etc. is likely to be due to a number of factors acting in combination, in particular the natural repeatability of the measurement, and more importantly the transverse position of the loaded wheel as it passes over the gauges. This latter effect is especially difficult to take account of since measurements of transverse position were made only at the beginning and end of the test length and with an accuracy of only plus or minus 5 cm,

Similarly, although the daily temperature variations are known, the results presented have not been normalised to a given temperature, and the observed scatter of results from a given group of gauges may be influenced by this.

The analysis so far has not attempted to distinguish between gauges of different type or method of installation. Any such differences are masked by the effects of other variables, and further analysis is required if they are to be identified.

Taken as a whole, the results tend to show that the measurements obtained by most teams are similar, with data from one team evidently at the bottom of the range and another at the top. The scatter of results, however, makes it impossible to draw more than this broad conclusion.

With these points in mind it was decided that the results should be subjected to a more detailed analysis as described in paragraph VI.2 below.

VI.1.6 Results from the BISON gauges

Measurements with the only pair of BISON gauges installed were carried out only for the first two days of the test programme on a total of 22 vehicle passages (see annex B.18 for the results). To assist in monitoring the gauges a portable storage oscilloscope was connected to the BISON meter output and a direct calibration of voltage output to amplitude was determined. Changes in voltages associated with each passage were manually recorded, converted to amplitude changes, and strains were approximated using amplitude strain relationships contained in the BISON meter operations manual. A detailed analysis of the data is not possible in view of the reduced number of single values and the different factors contributing to a dispersion of the results. A comparison of the data indicates however a tendency to obtain larger strain values than those obtained by direct measurement.

VI.2 FURTHER ANALYSIS OF THE RESULTS

In this second phase of analysis, the main purpose was to reduce or eliminate the effects of those independent variables present during the collection of data, notably pavement temperature and transverse position of the vehicle. The following paragraphs describe each part of the analysis and the reasons for it.

VI.2.1 Normalisation of results to a single pavement temperature

Because of the daily variation in pavement temperature alone, comparisons between the data measured by different groups of gauges and by different teams are difficult; measurements of temperature made by three teams indicate differences in temperature from one part of the test length to another, and small differences in the rate of change of temperature throughout the period of the experiments.

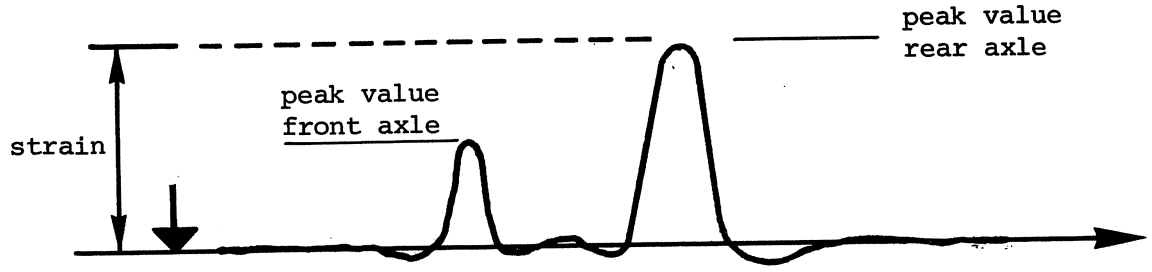


Figure VI.1 Definition of the strain value chosen for the analysis of the data

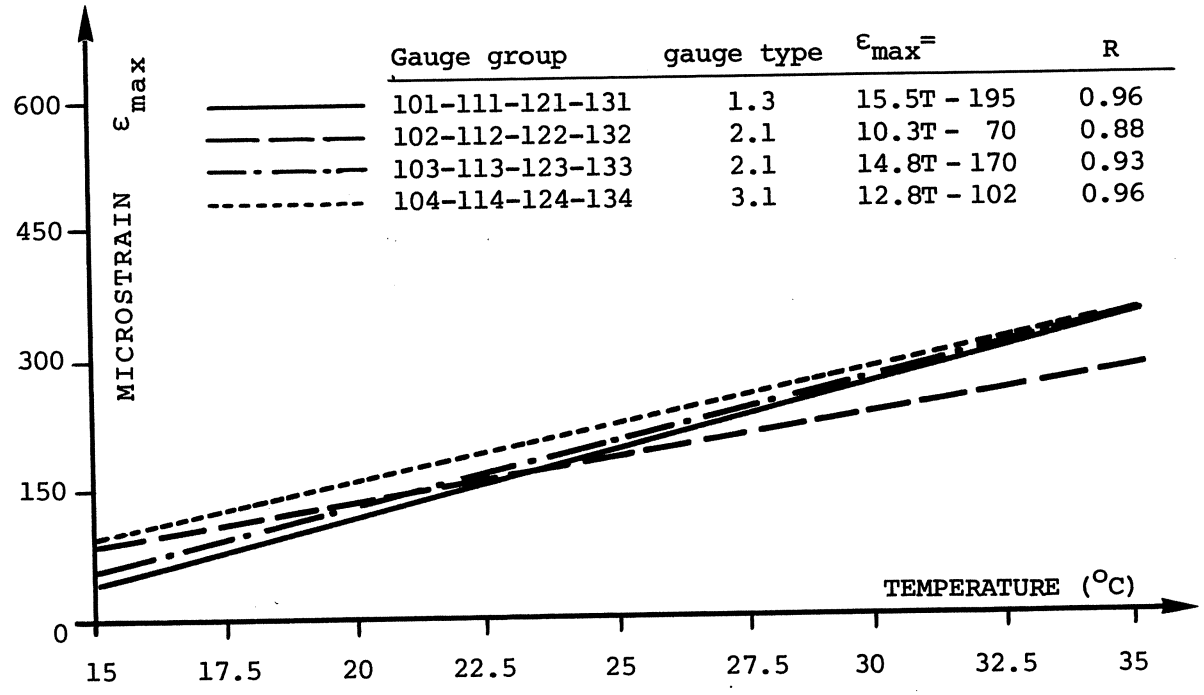


Figure VI.2 Relationship between measured strain and pavement temperature, team no. 1

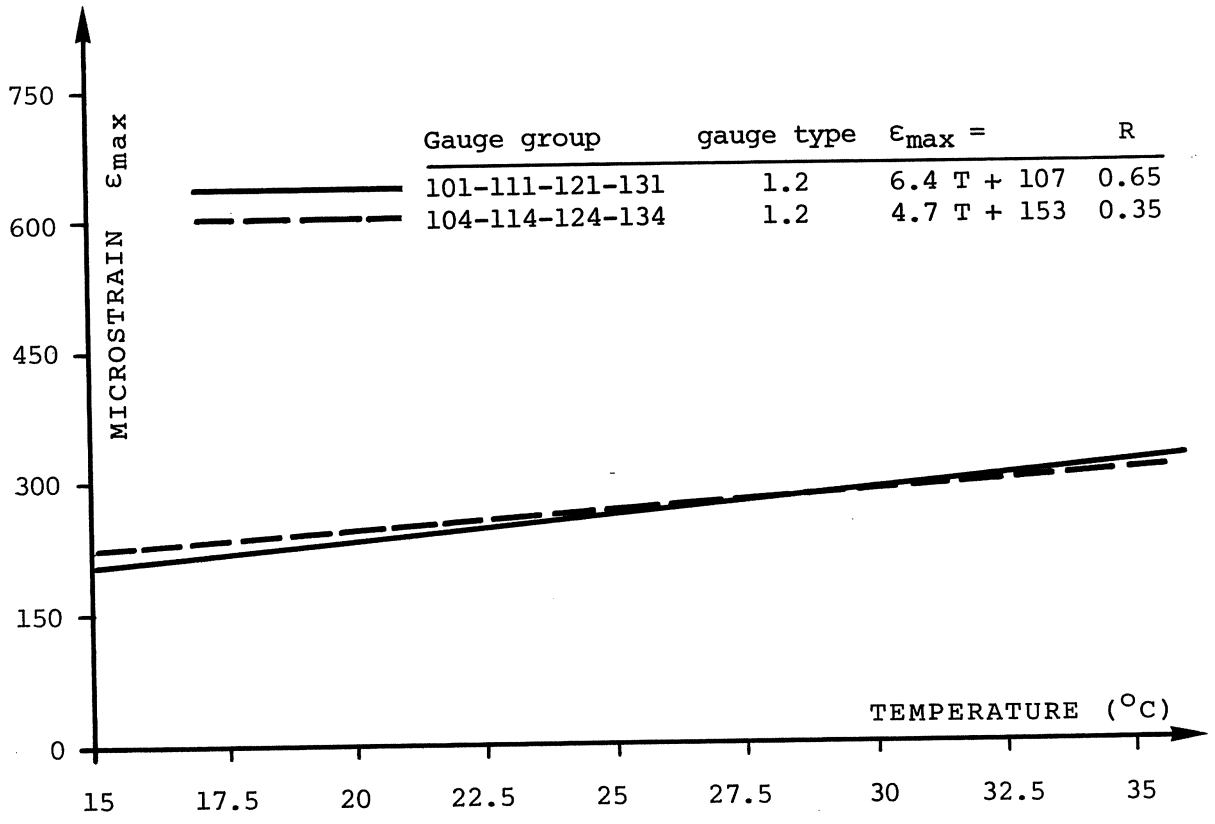


Figure VI.3 Relationship between strain and pavement temperature, team no. 2

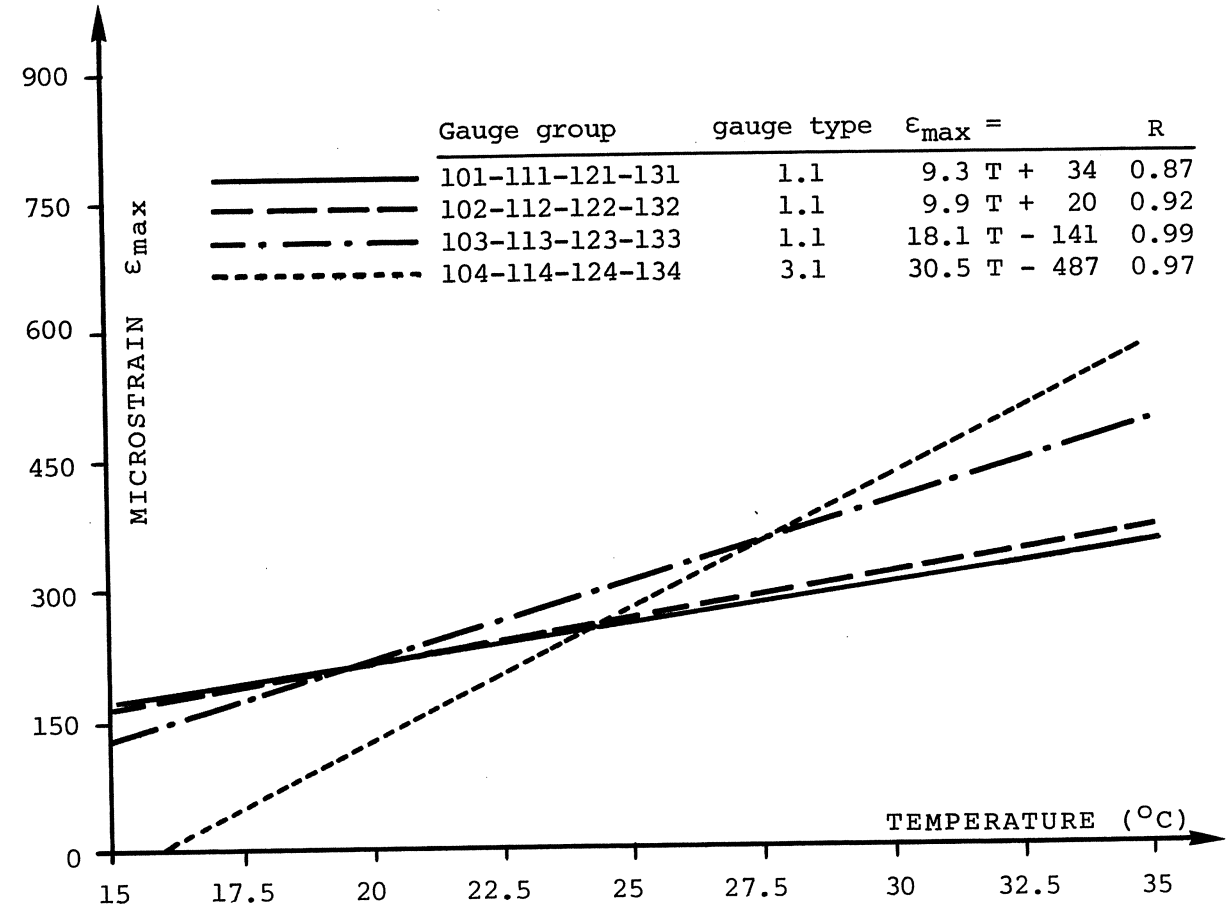


Figure VI.4 Relationship between strain and pavement temperature, team no. 3

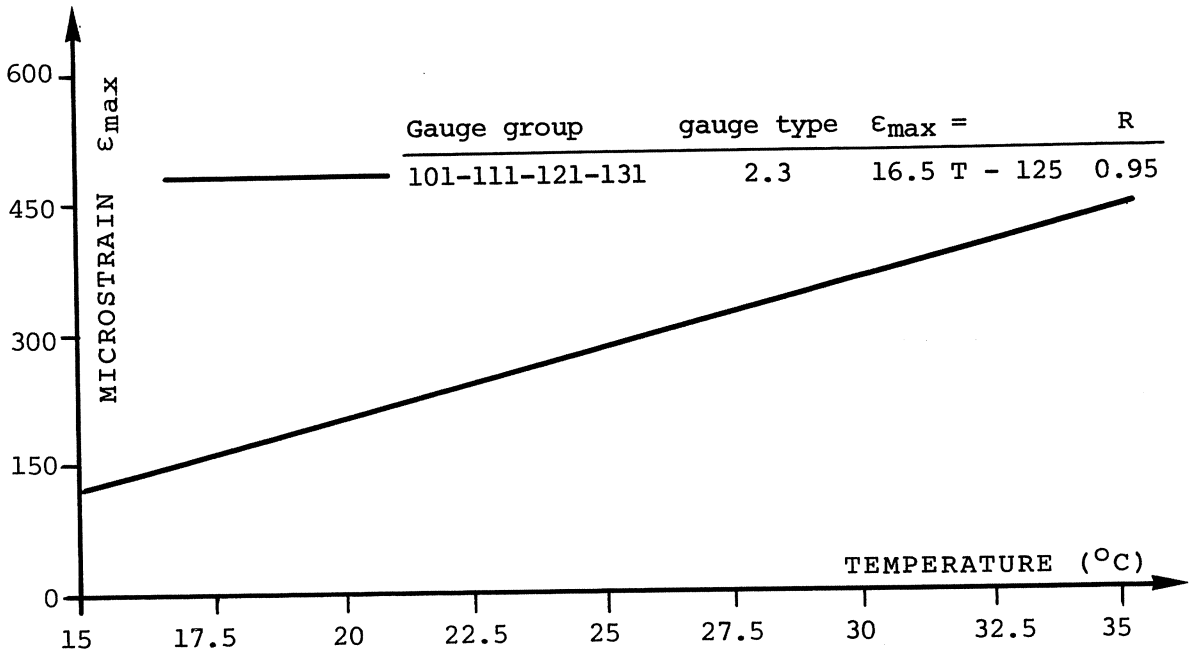


Figure VI.5 Relationship between strain and pavement temperature, team no. 4

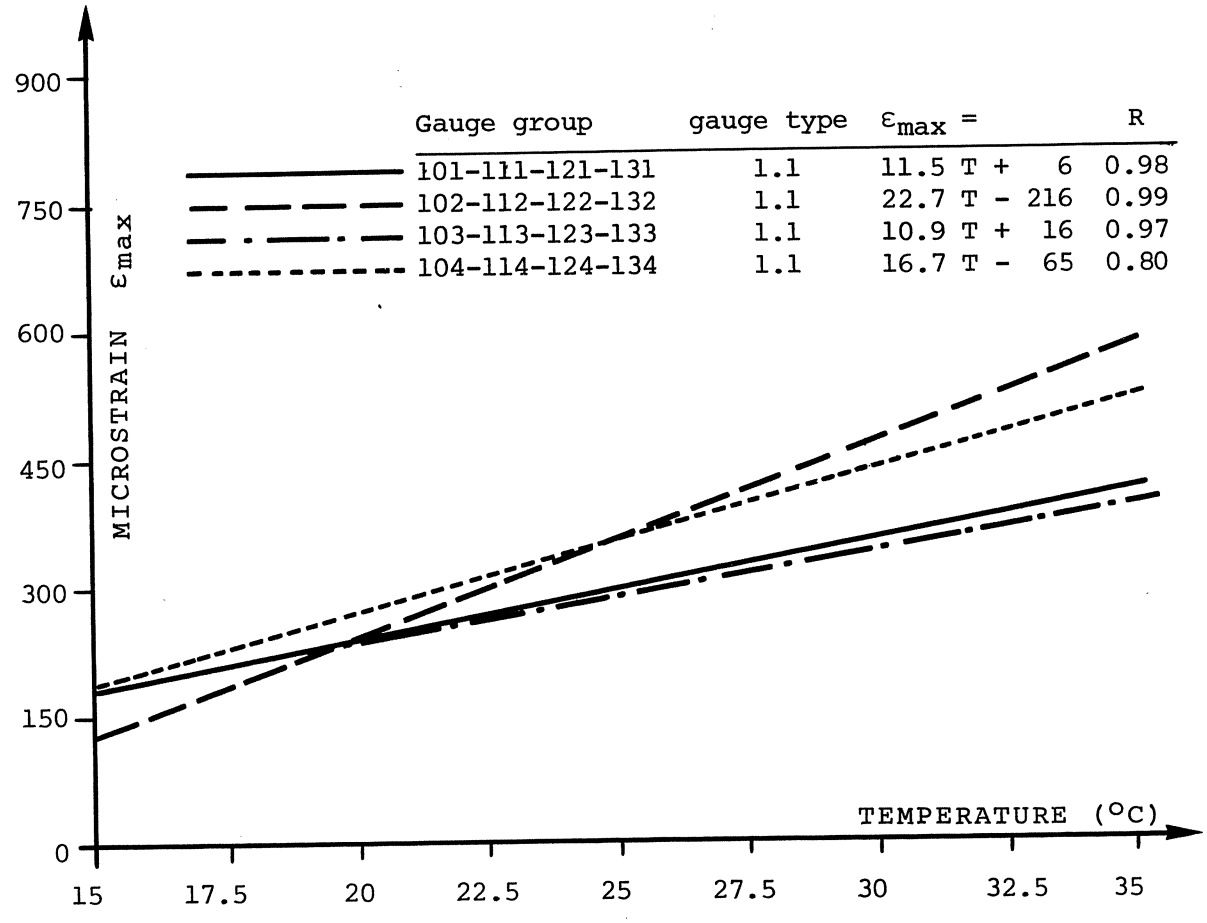


Figure VI.6 Relationship between strain and pavement temperature, team no. 5

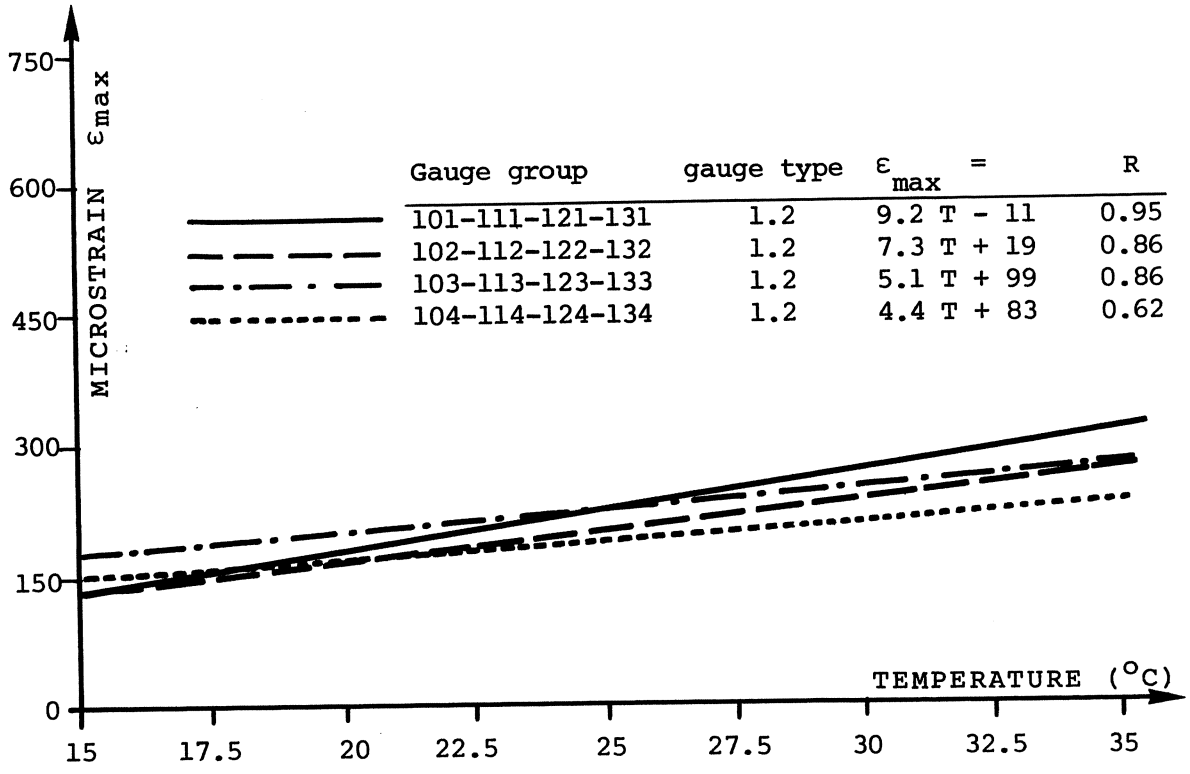


Figure VI.7 Relationship between strain and pavement temperature, team no. 6

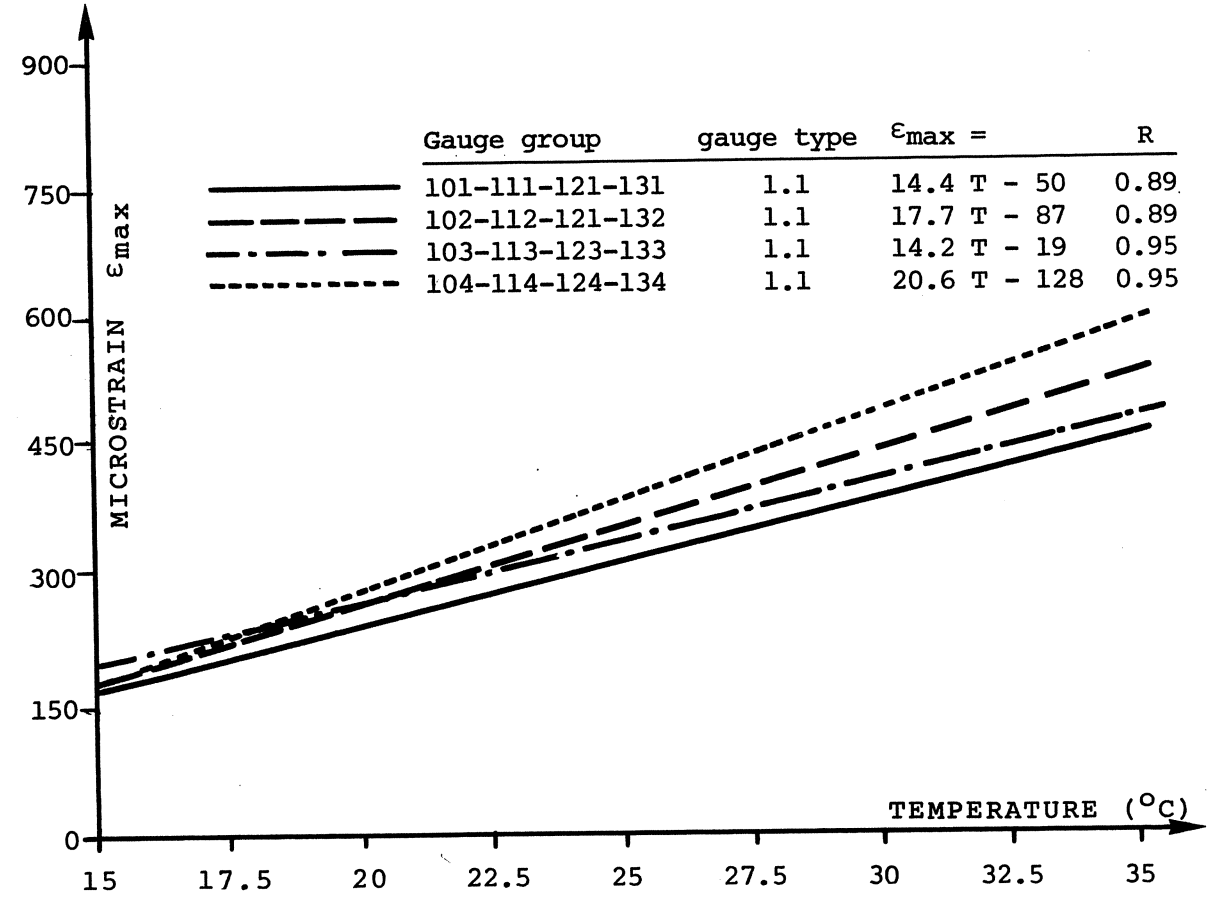


Figure VI.8 Relationship between strain and pavement temperature, team no. 7

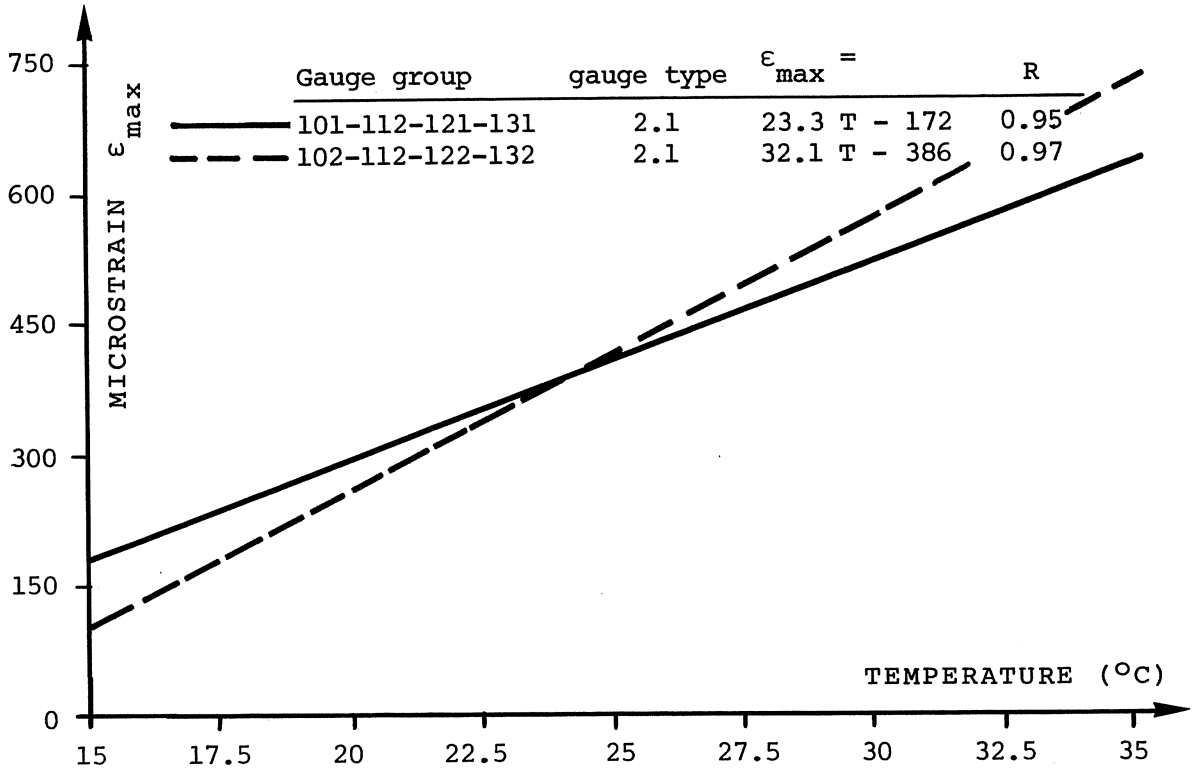


Figure VI.9 Relationship between strain and pavement temperature, team no. 8

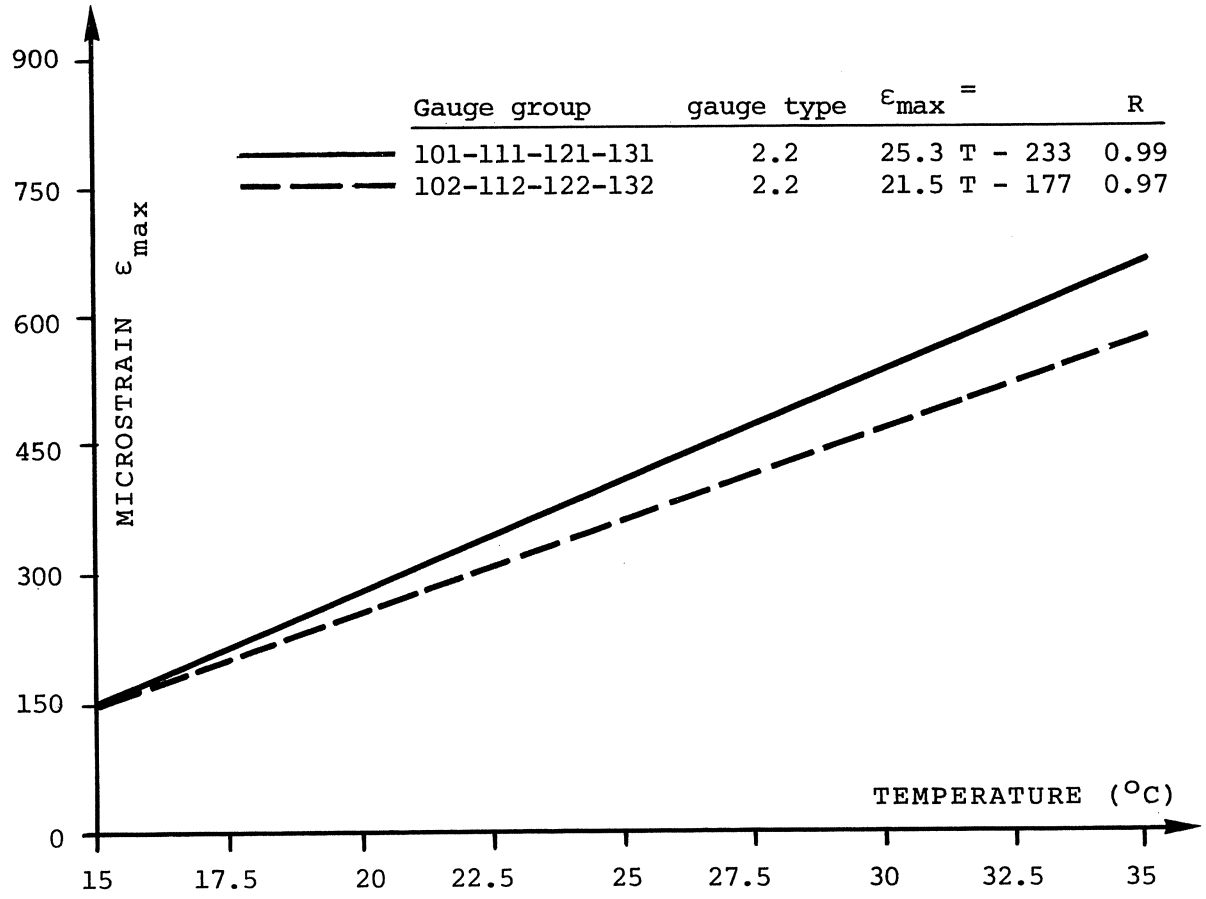


Figure VI.10 Relationship between strain and pavement temperature, team no. 9

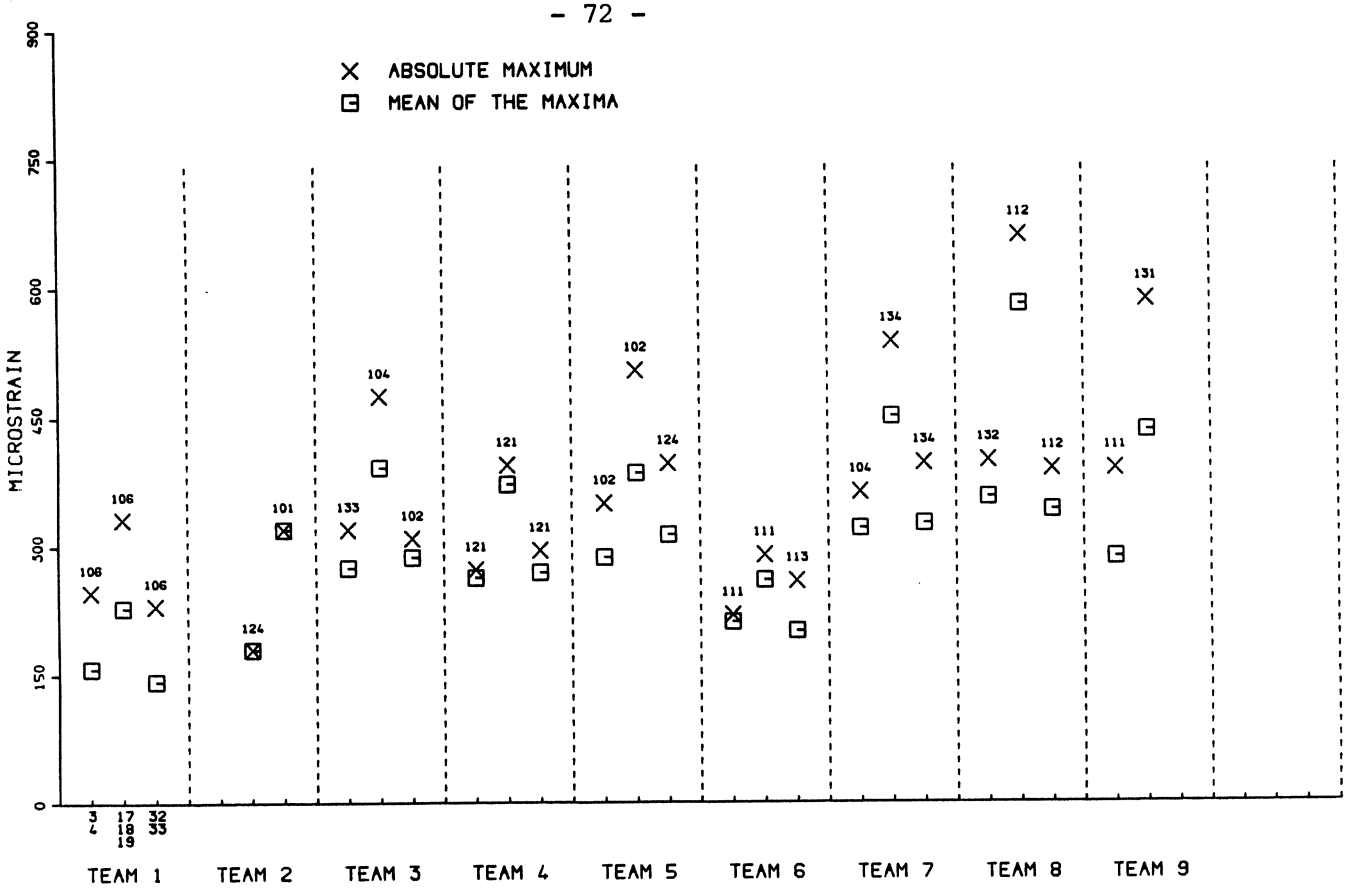


Figure VI.11 Variation of strain maxima with site position

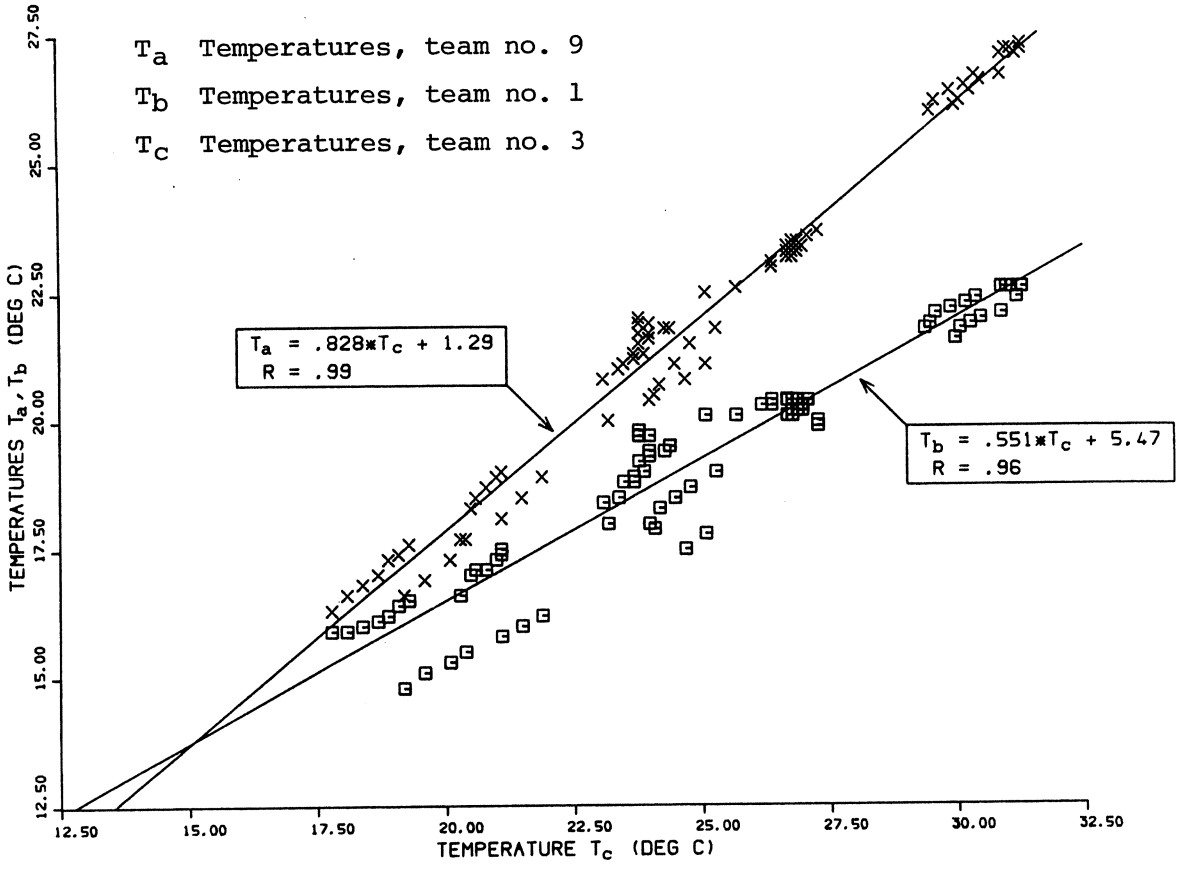


Figure VI.12 Variation of temperatures team by team

Comparisons could be made more readily if the results were presented on the basis of a single standardised temperature. For this reason therefore an analysis was undertaken in which previous results (see para. VI.1.2) were used to convert measured strains to the strain which would have been recorded at 24°C., a temperature selected as being close to the centre of the range of pavement temperatures encountered during the tests.

VI.2.2 Variation of measured strain with type of gauge

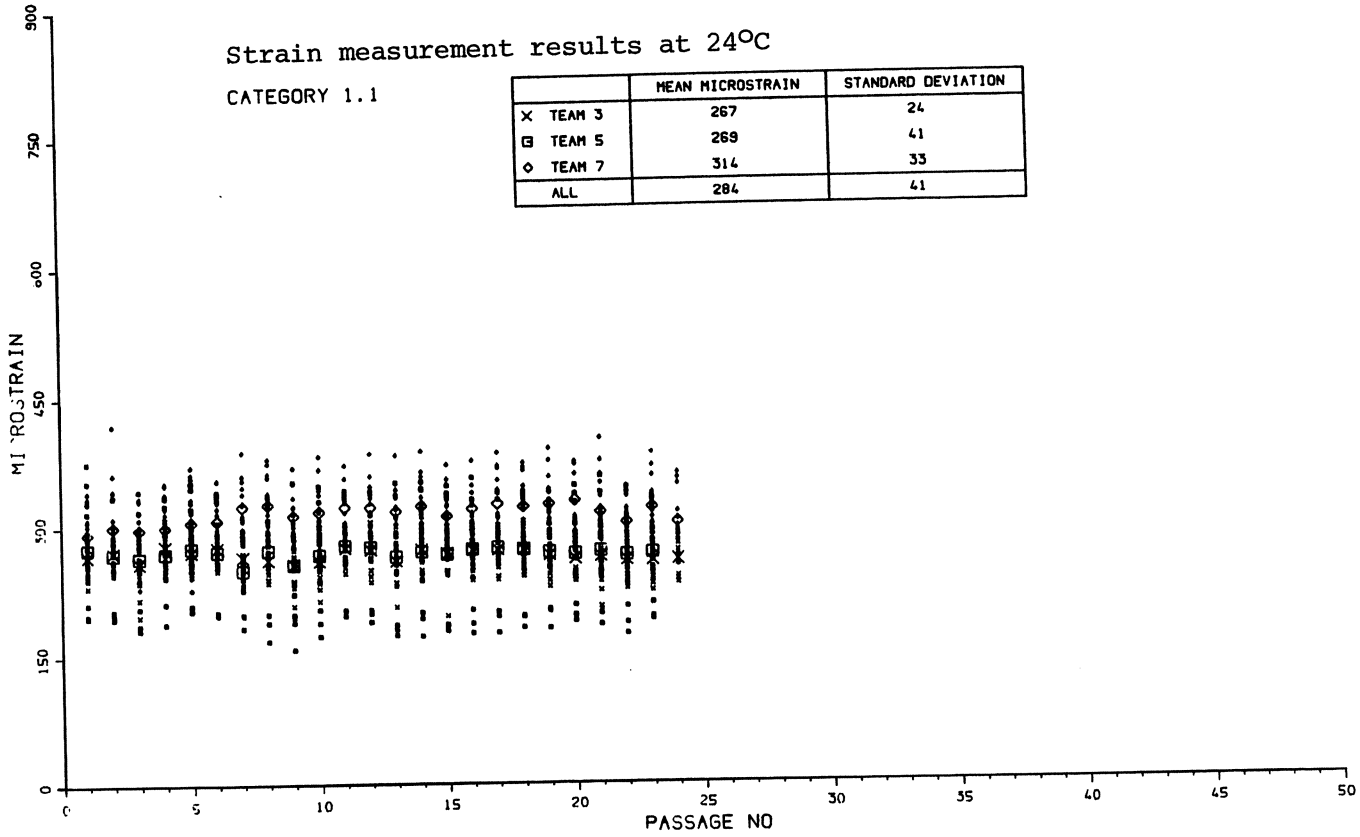
In an earlier section of this report (Ch. III), the different gauges used in the tests have been categorised according to their method of construction or method of installation. An analysis was therefore made which would illustrate any differences in performance between different categories of strain gauge. The data mentioned in paragraph VI.2.1 were first separated, gauge group by gauge group, into those of one category or another. All gauge groups of a given category were then plotted together, as shown in the example of Fig. VI.13 and VI.14 including all the measurements made. In these graphs, the strains measured during each of the three days of testing were standardised and plotted separately; the mean and standard deviation of strain for the gauges of each team were noted on each of the graphs.

Part of the dispersion of results in these graphs is due to variations in the transverse position of vehicles as they pass down the gauge line. As stated earlier the maximum strain recorded by a gauge group probably represents the strain directly or almost directly beneath the wheel. The examples on Fig. VI.15 and VI.16 therefore show the means of the standardised maximum strains recorded by each of the vehicles A, B and C (together with the maxima themselves) as a function of passage number.

Differences between the loading characteristics of vehicles A, B and C may account for some of the observed differences in measured strains. For each gauge, of each team, therefore, the absolute maximum strain recorded during each passage has been extracted from the results, standardized to 24°C, and plotted against passage number as shown in Figures VI.17 to VI.35. The mean and standard deviation of the absolute maxima are also noted on each graph.

VI.2.3 The influence of standardising temperature on calculated strains

Because the strain-temperature curves derived earlier for each team's groups of gauges have different slopes, and also because of variations in the pavement temperature measured along the test site, the choice of standardizing temperature may influence comparisons between different gauge groups or categories. For these reasons, the first part of the analysis described in paragraph VI.2.2 has been repeated using two other standardizing temperatures, 18°C and 30°C. The resulting graphs showing the variation of standardized strains with passage number are not included in this report.



Figures VI.13 Variation of standardised strain with gauge category

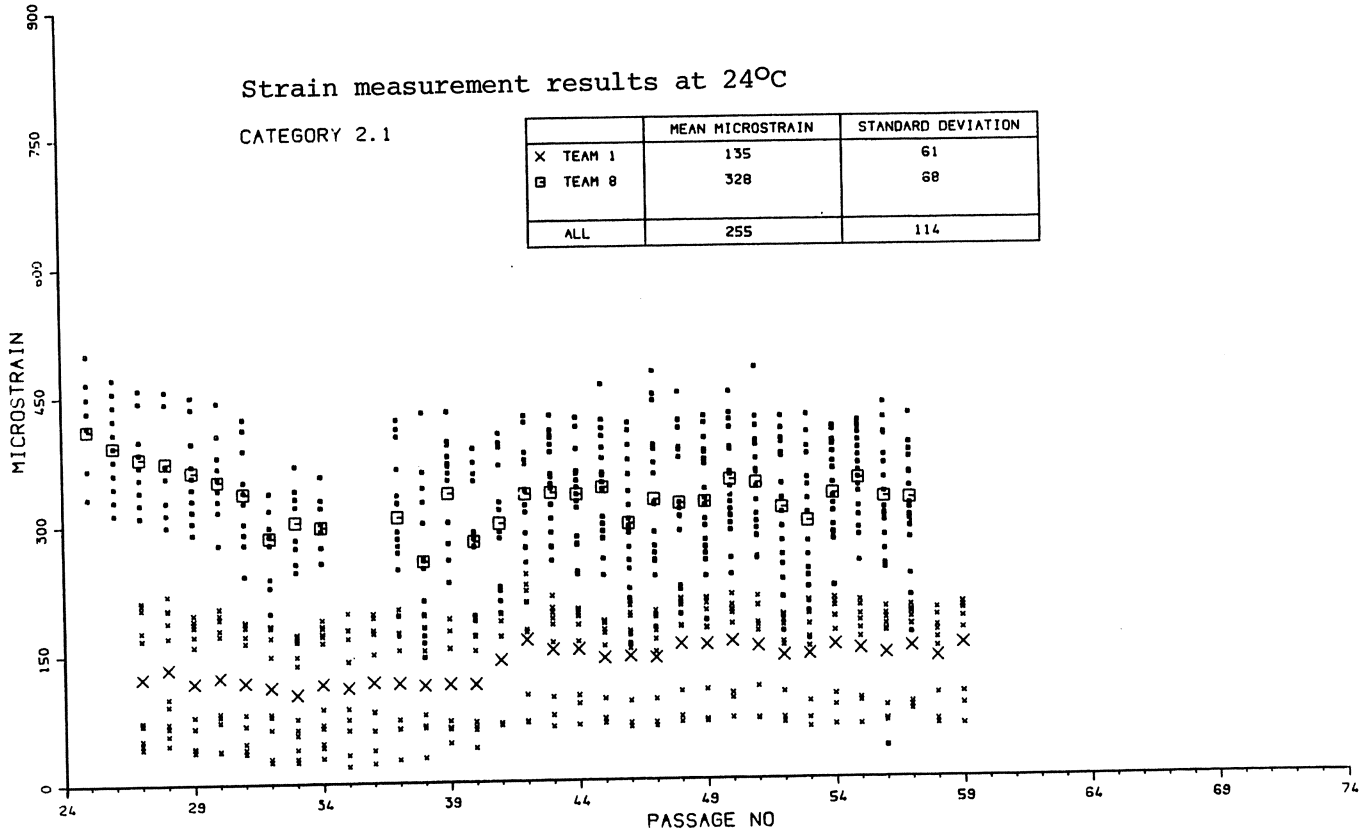


Figure VI.14 Variation of standardised strain with gauge category

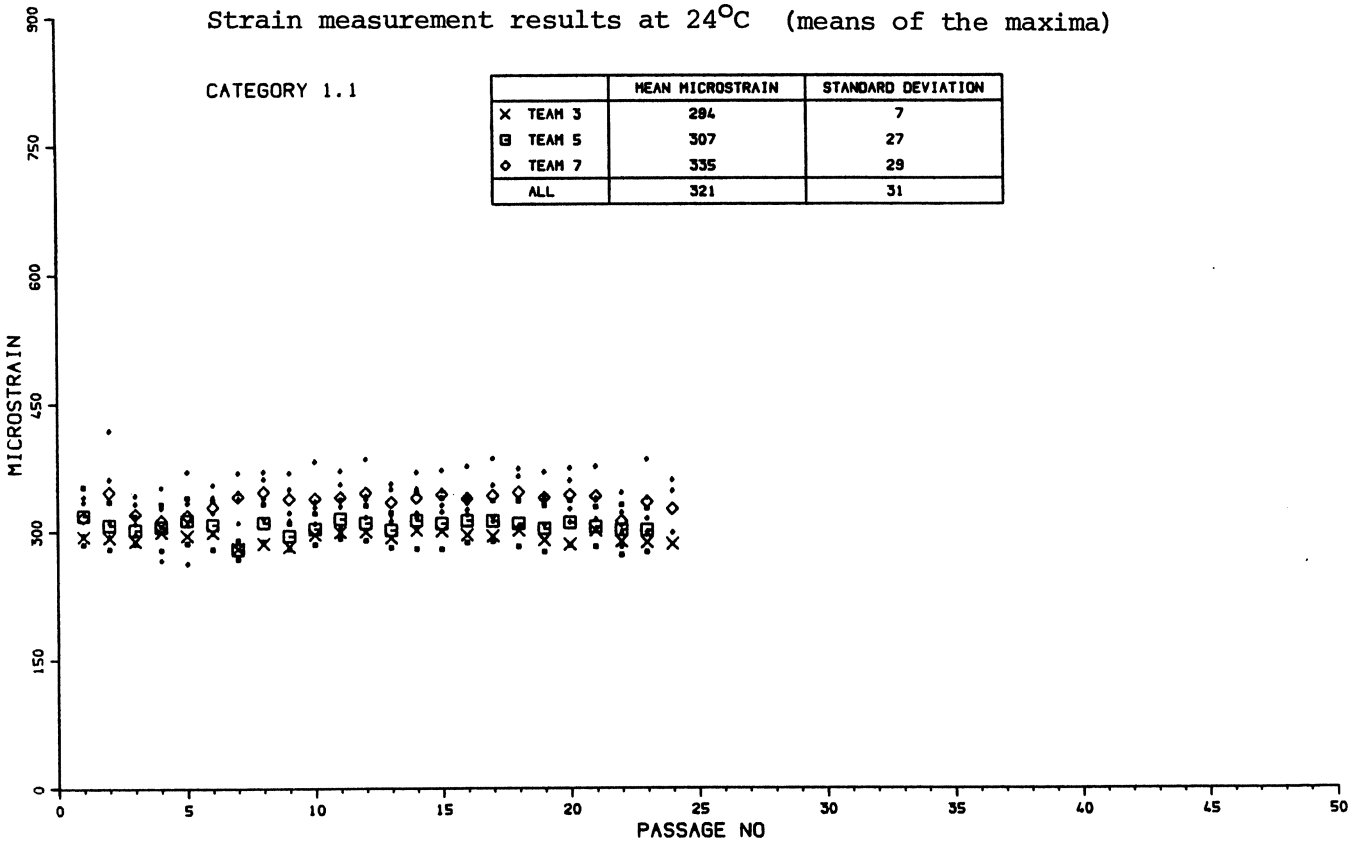


Figure VI.15 Variation of mean standardised strain with gauge category

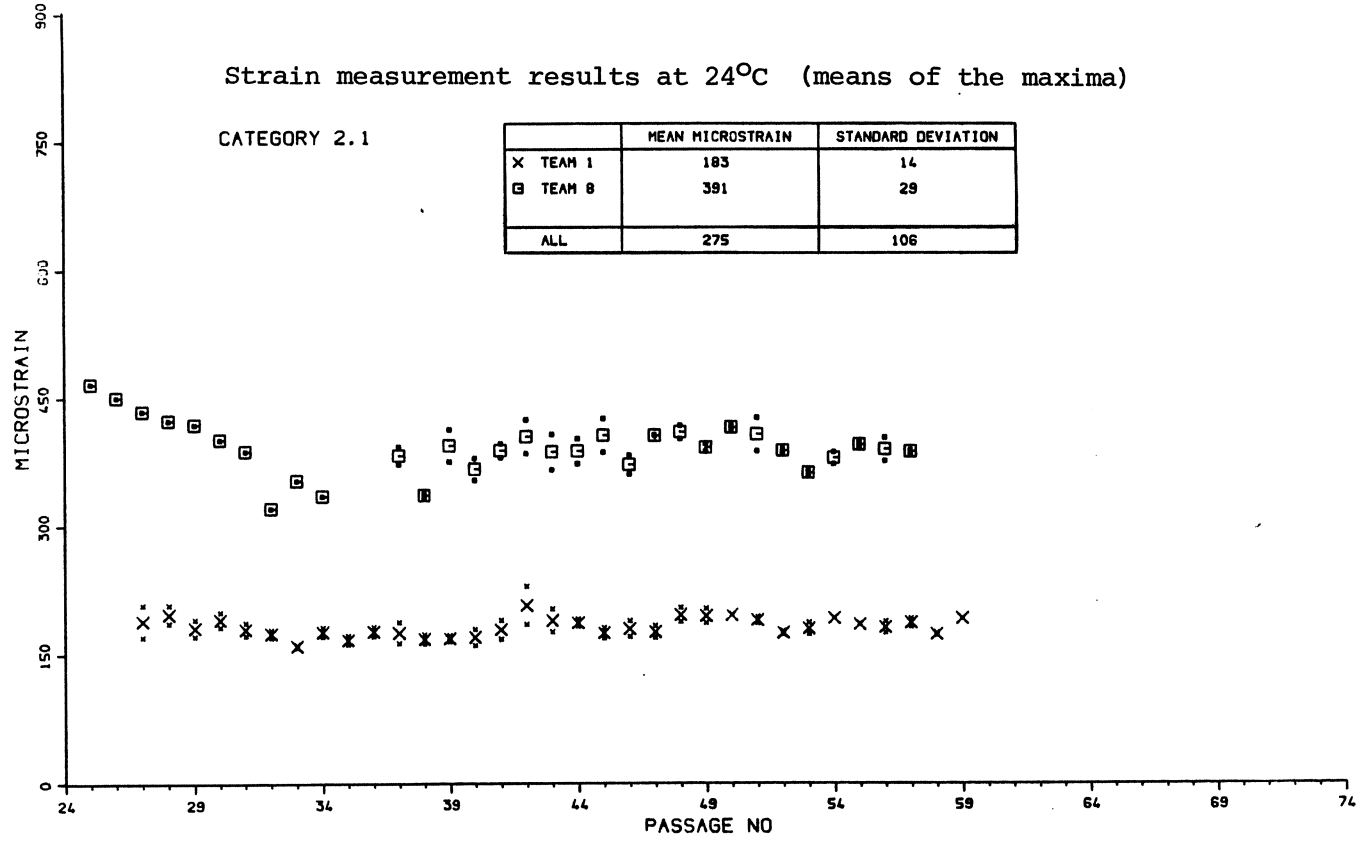


Figure VI.16 Variation of mean standardised strain with gauge category

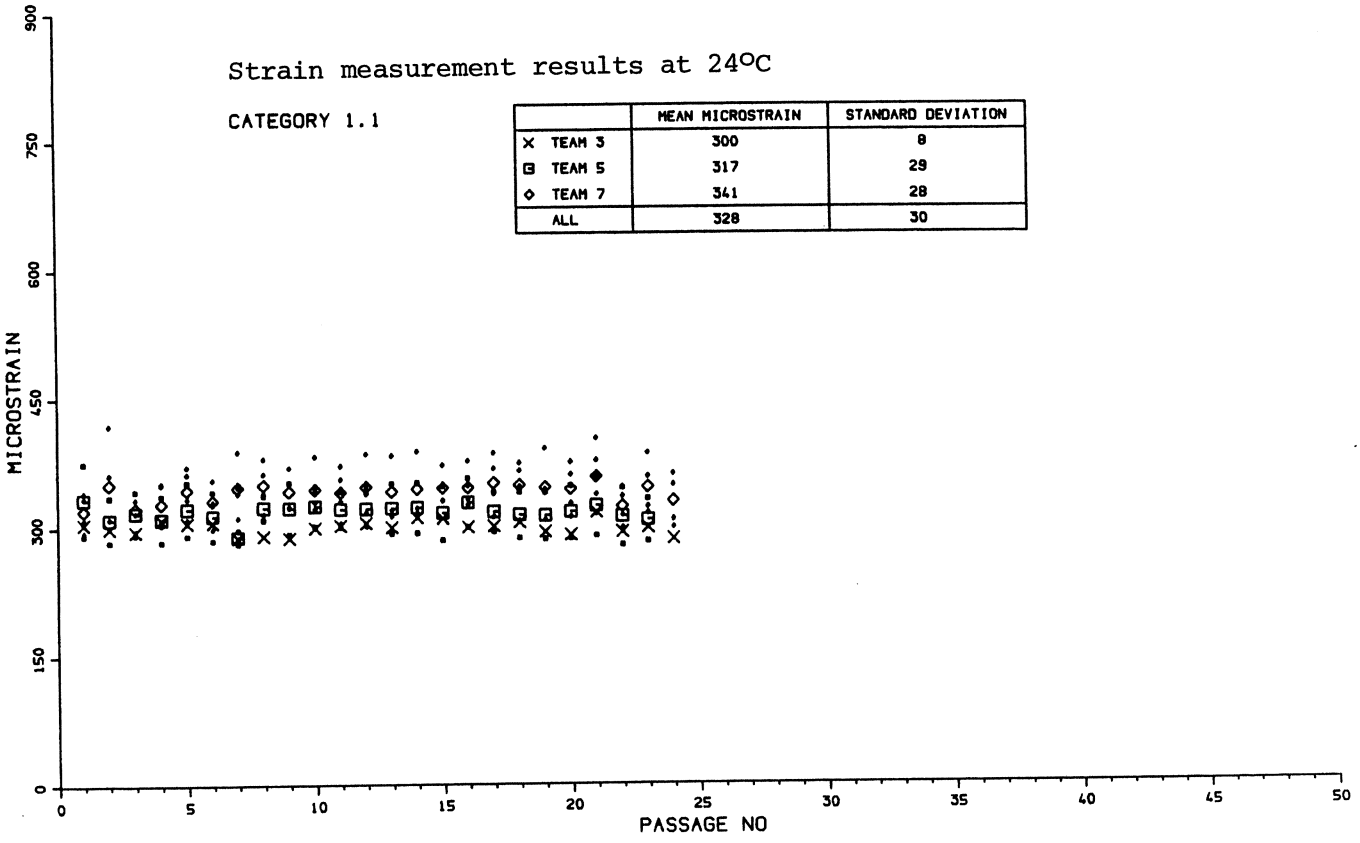


Figure VI.17 Variation of absolute maximum standardised strain with gauge category

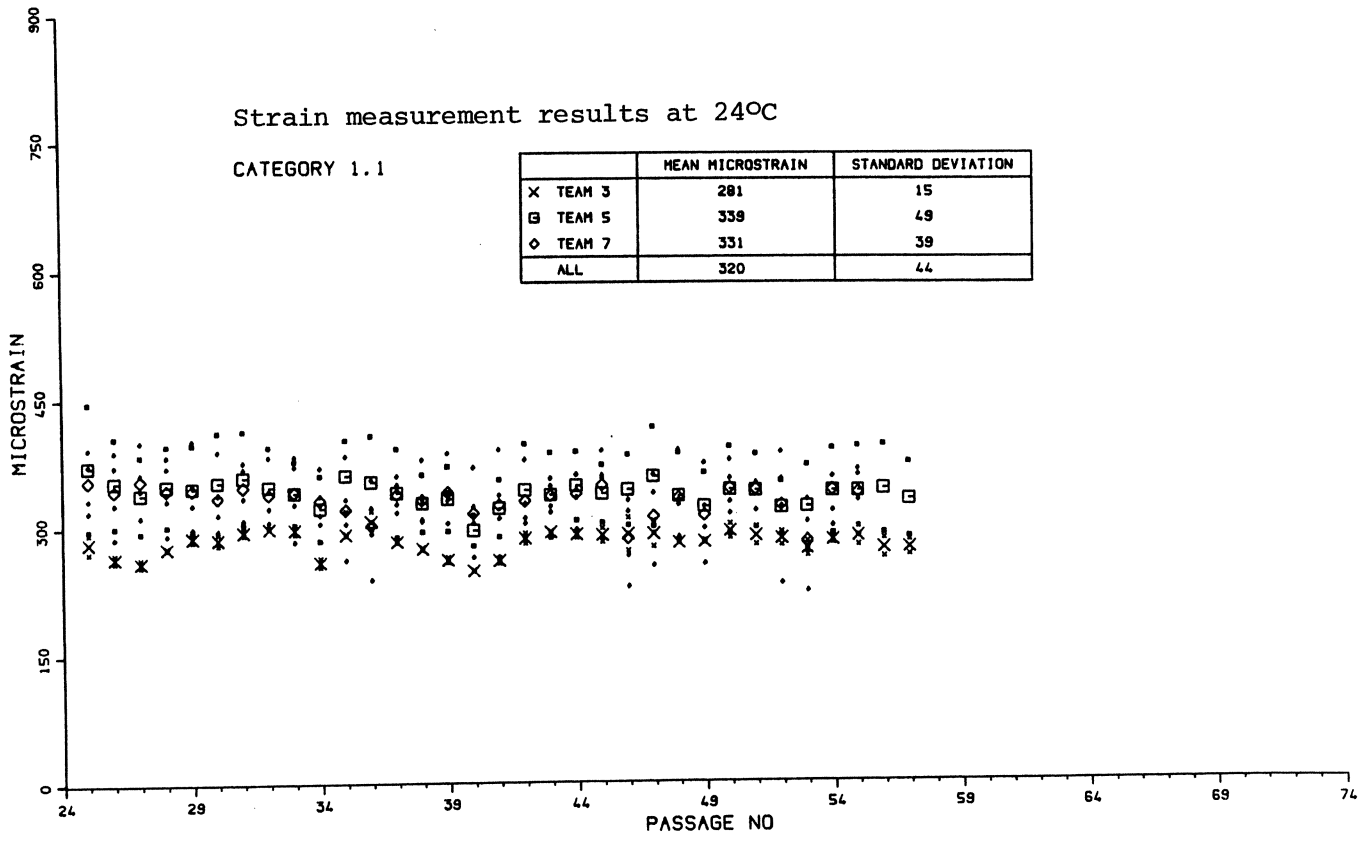


Figure VI.18 Variation of absolute maximum standardised strain with gauge category

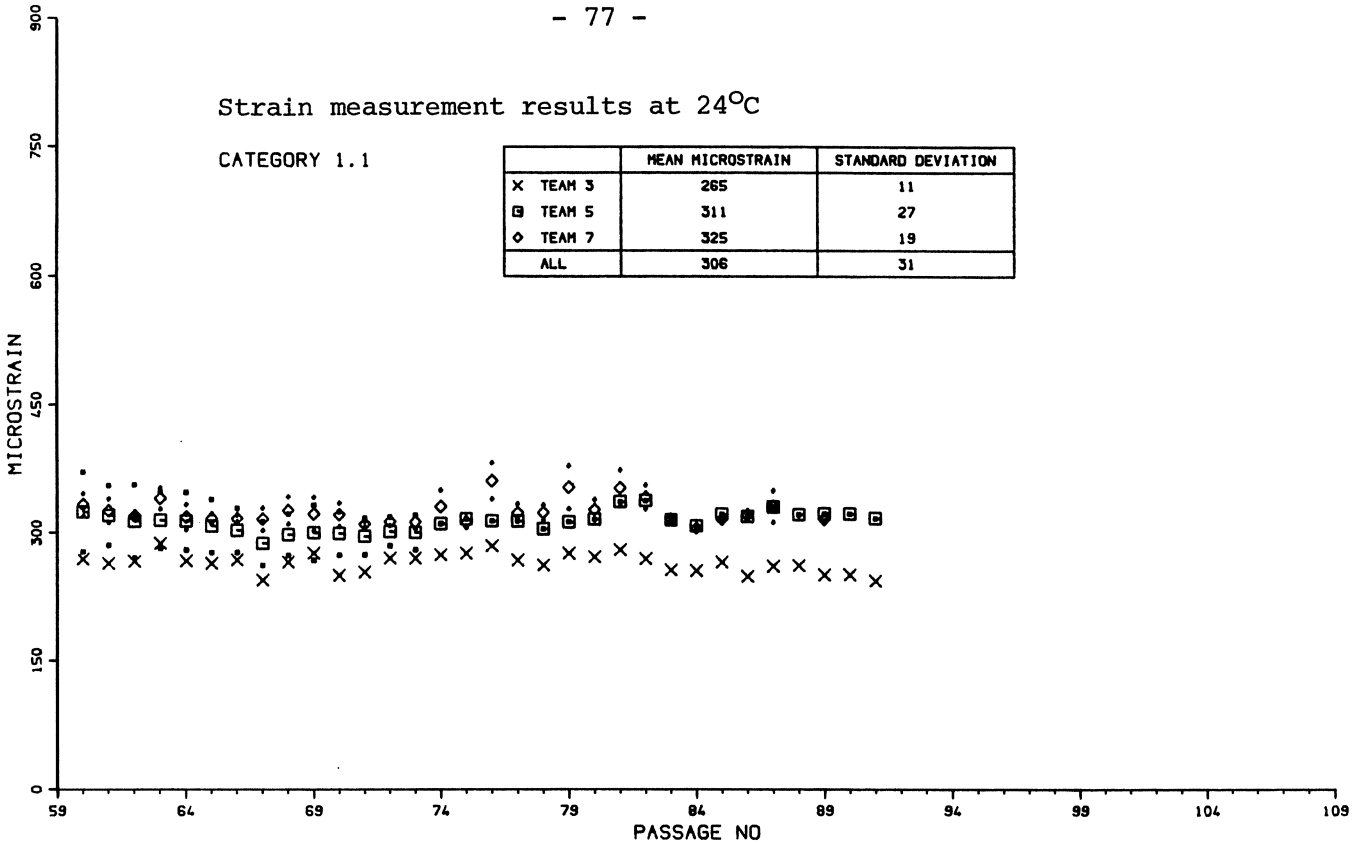


Figure VI.19 Variation of absolute maximum standardised strain with gauge category

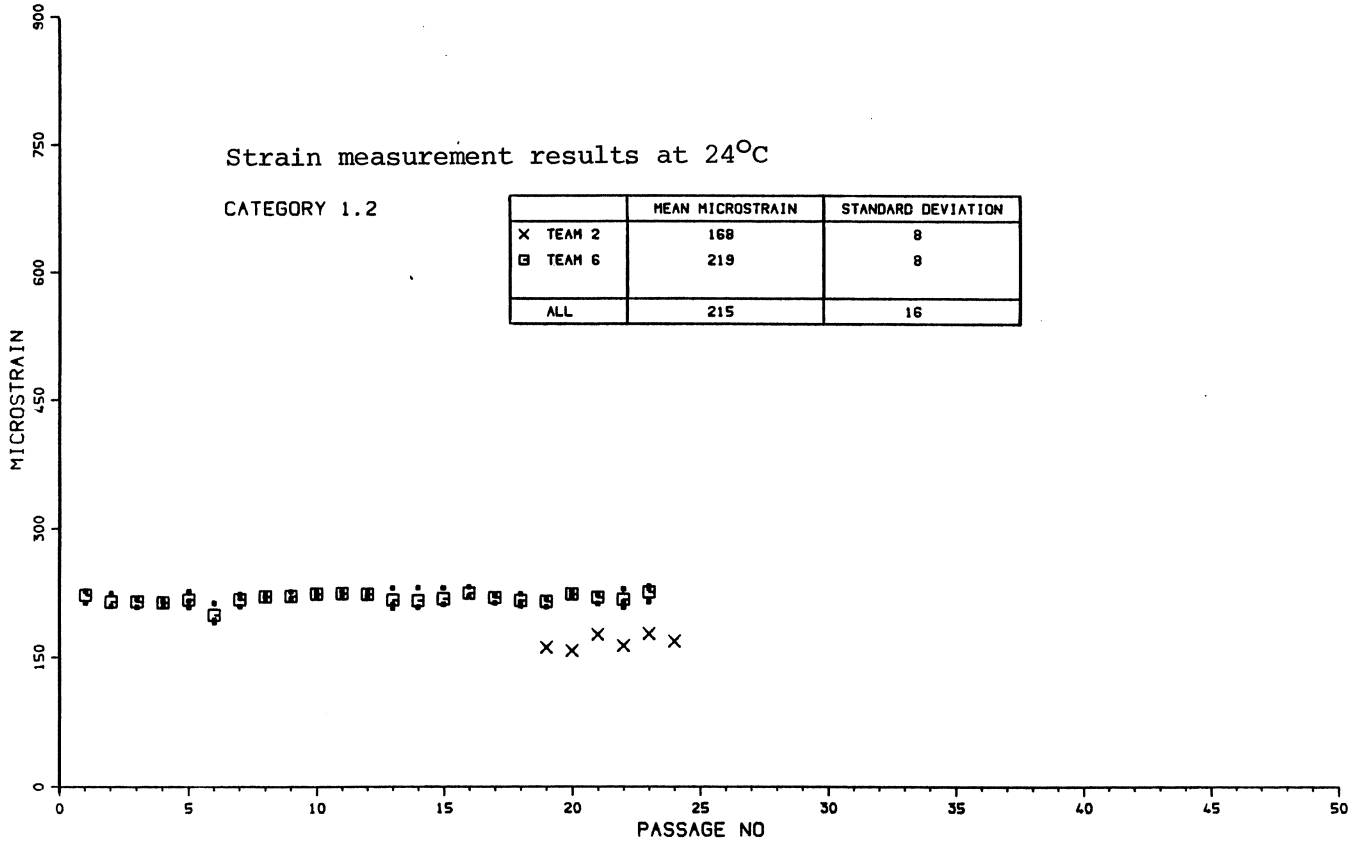


Figure VI.20 Variation of absolute maximum standardised strain with gauge category

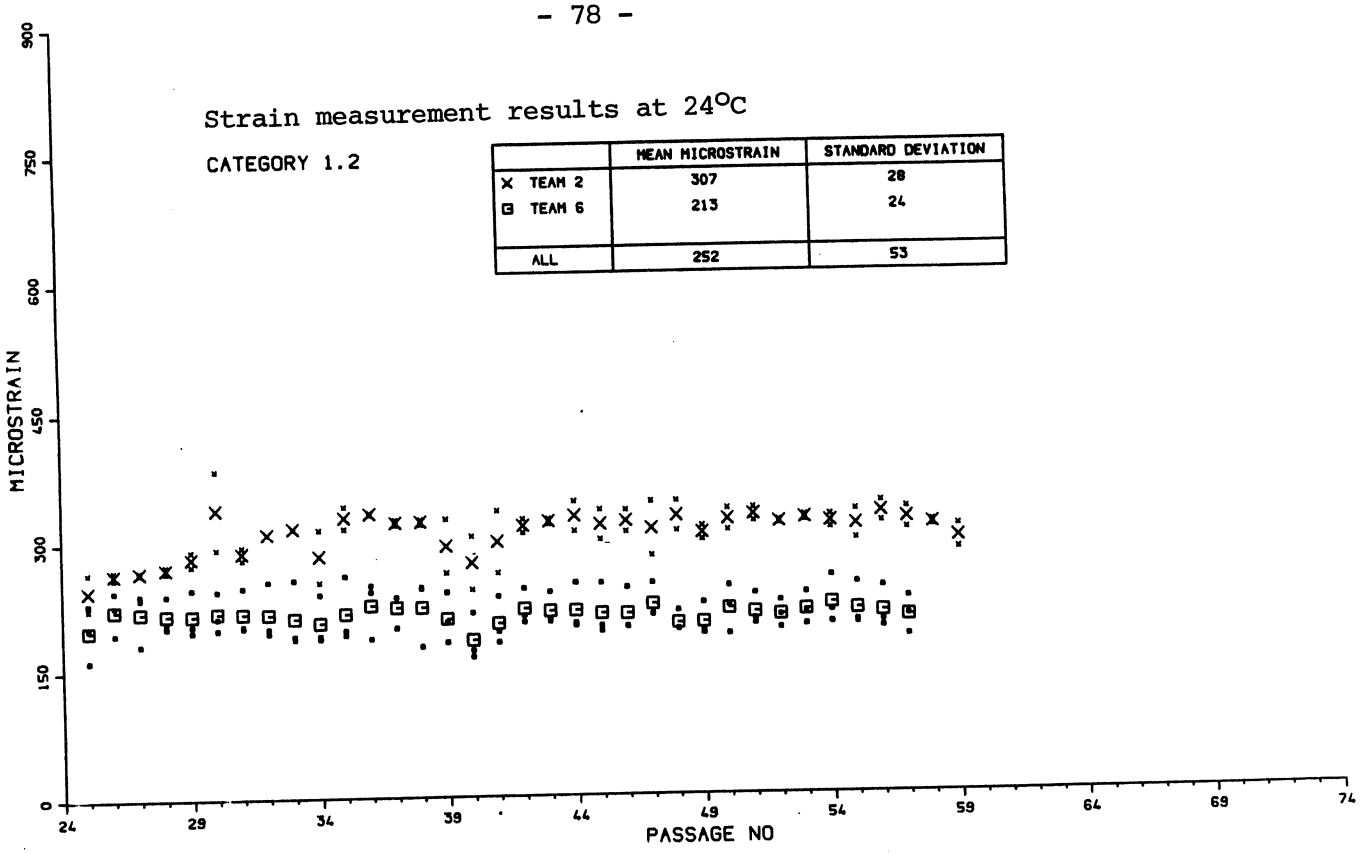


Figure VI.21 Variation of absolute maximum standardised strain with gauge category

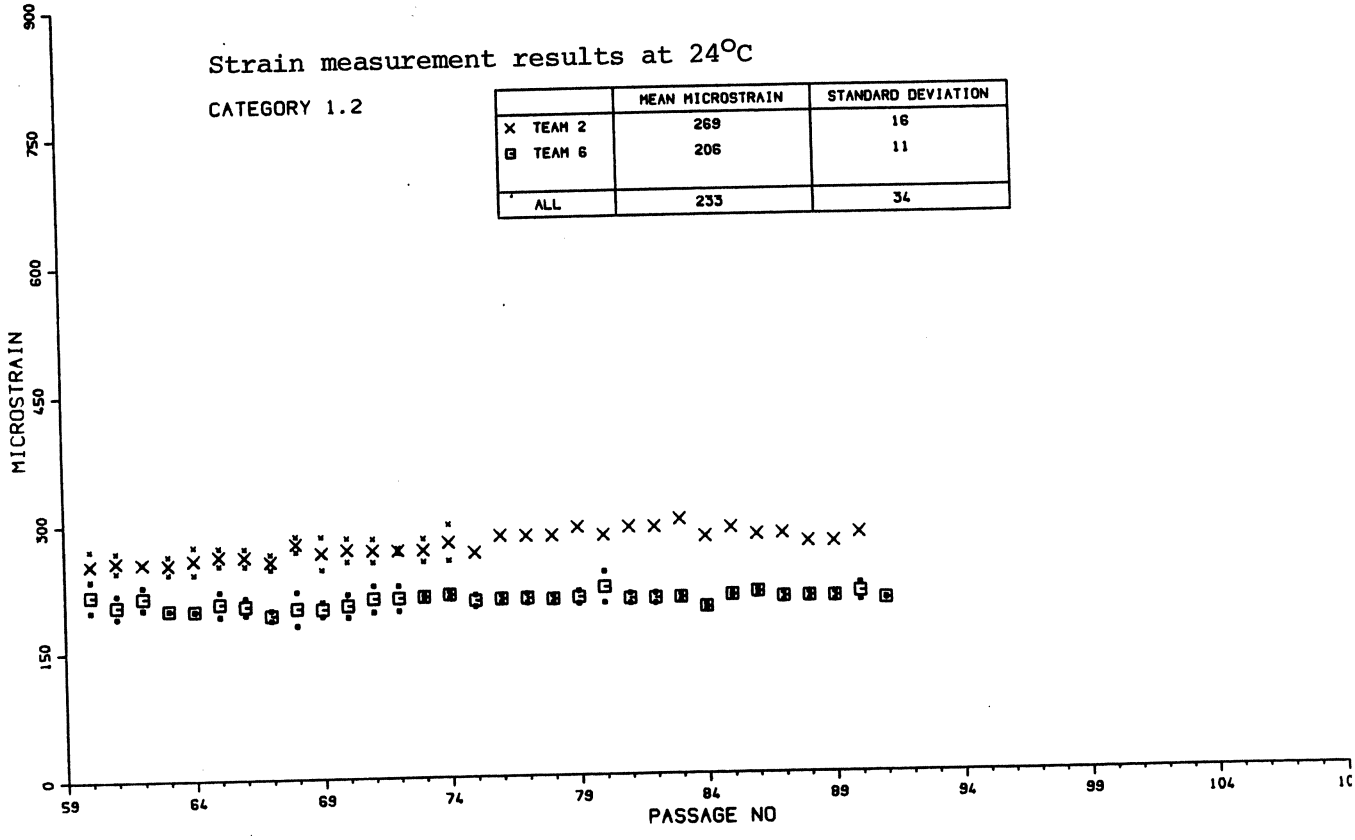


Figure VI.22 Variation of absolute maximum standardised strain with gauge category

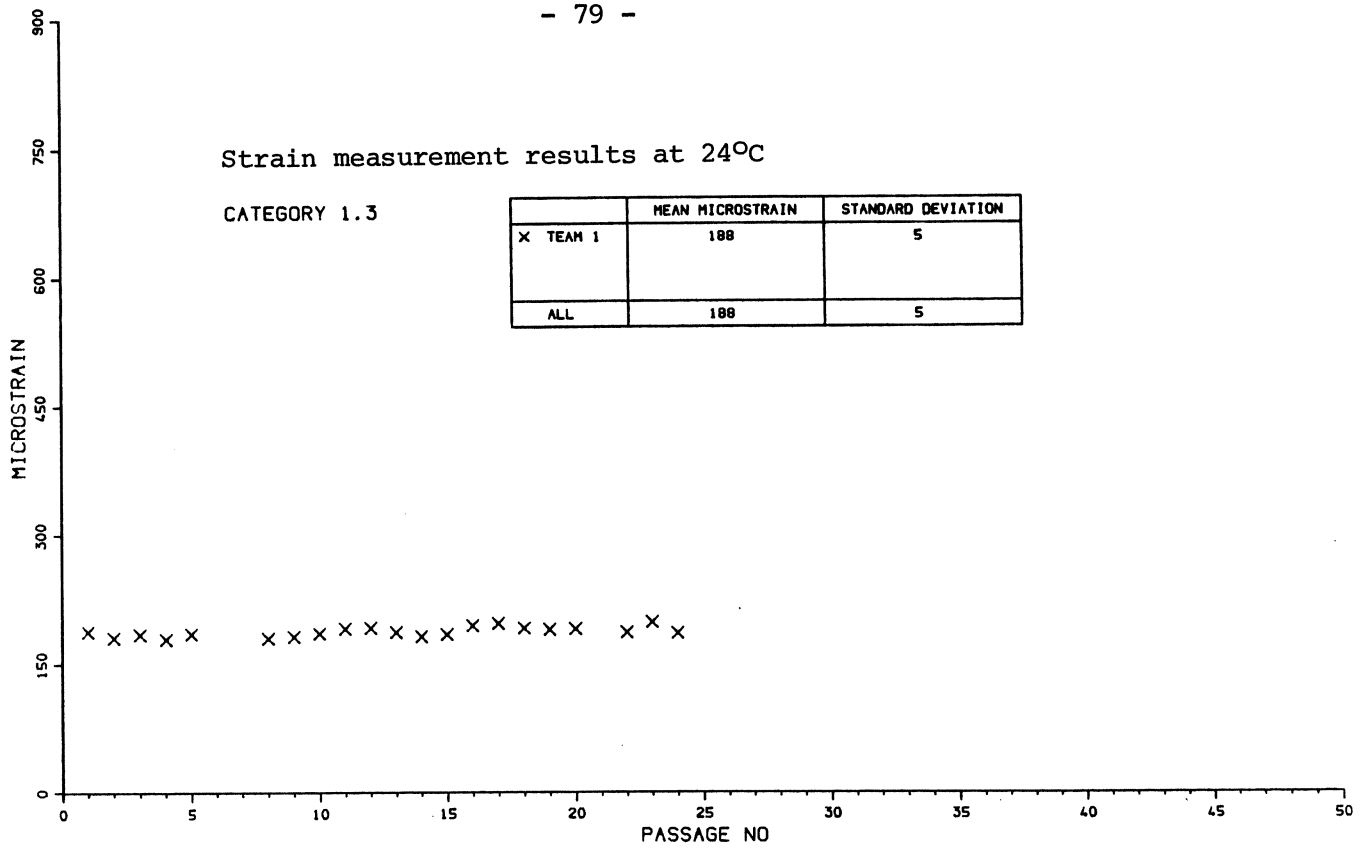


Figure VI.23 Variation of absolute maximum standardised strain with gauge category

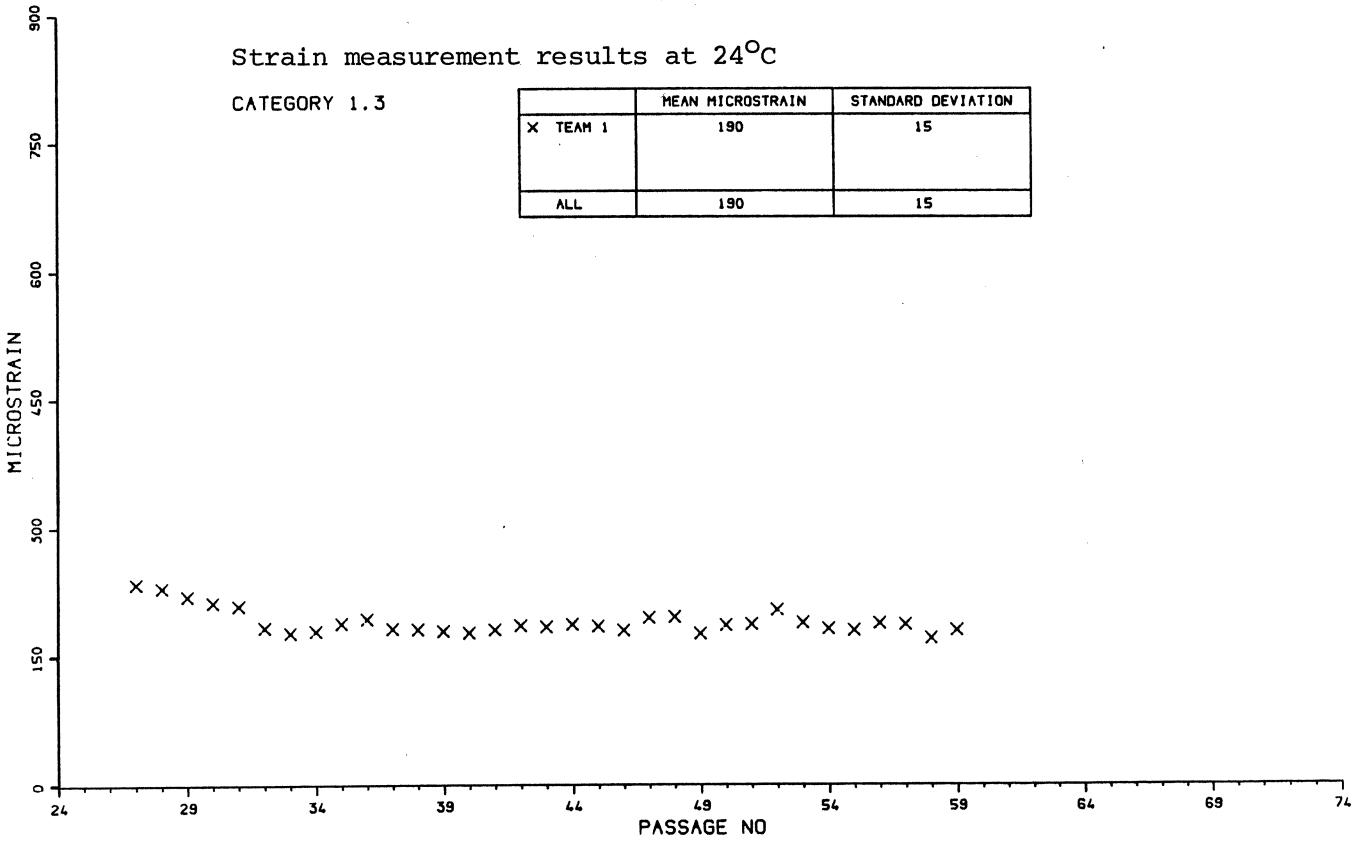


Figure VI.24 Variation of absolute maximum standardised strain with gauge category

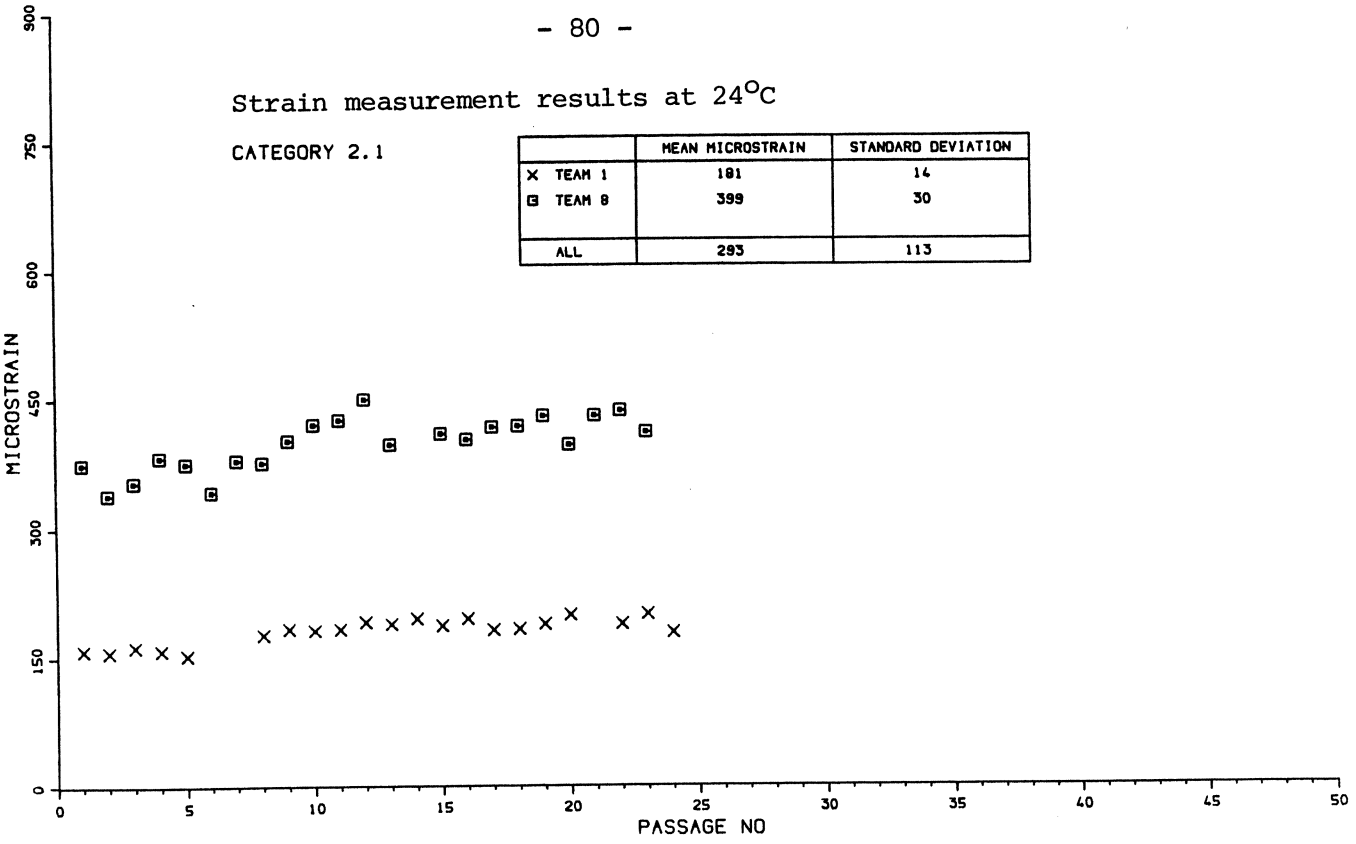


Figure VI.25 Variation of absolute maximum standardised strain with gauge category

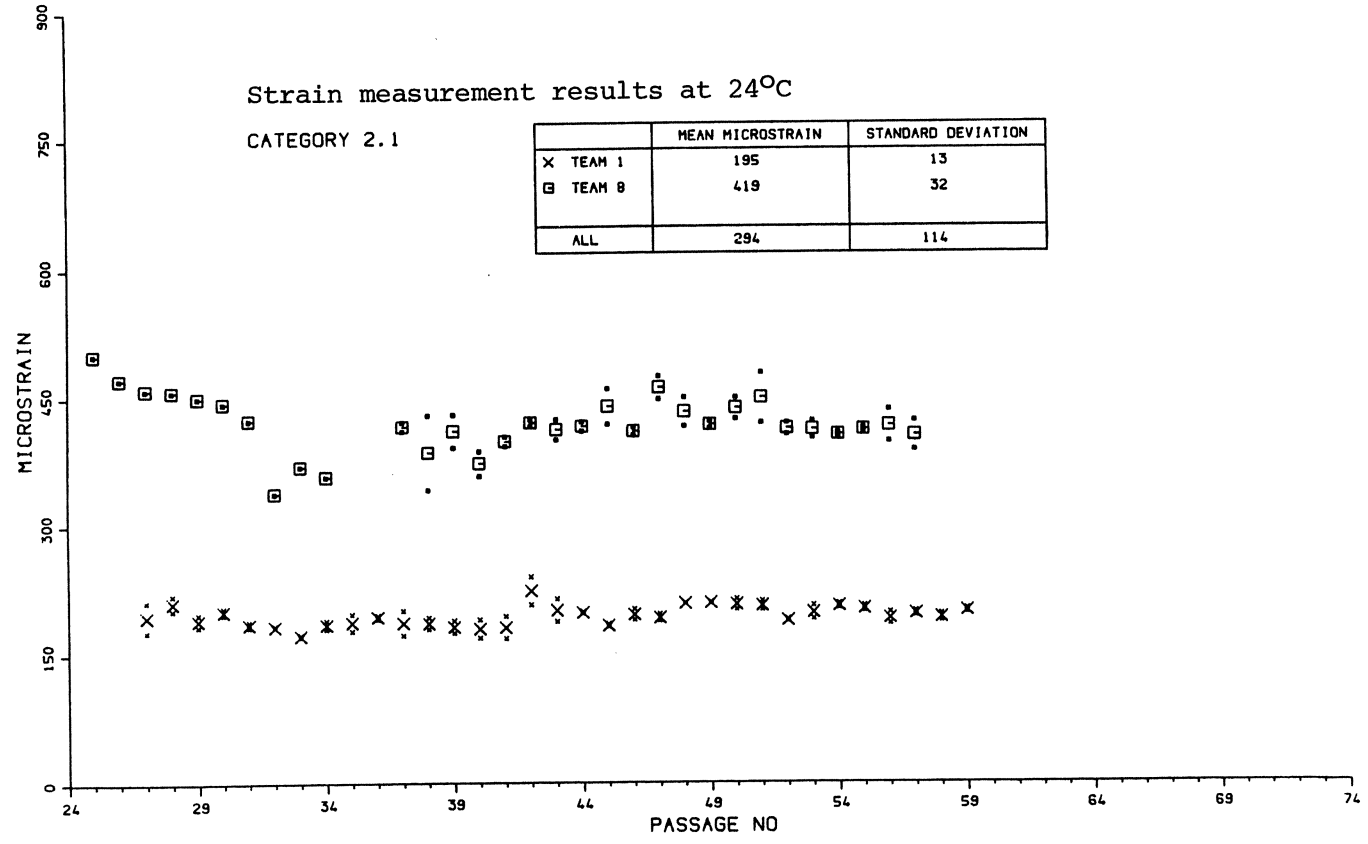


Figure VI.26 Variation of absolute maximum standardised strain with gauge category

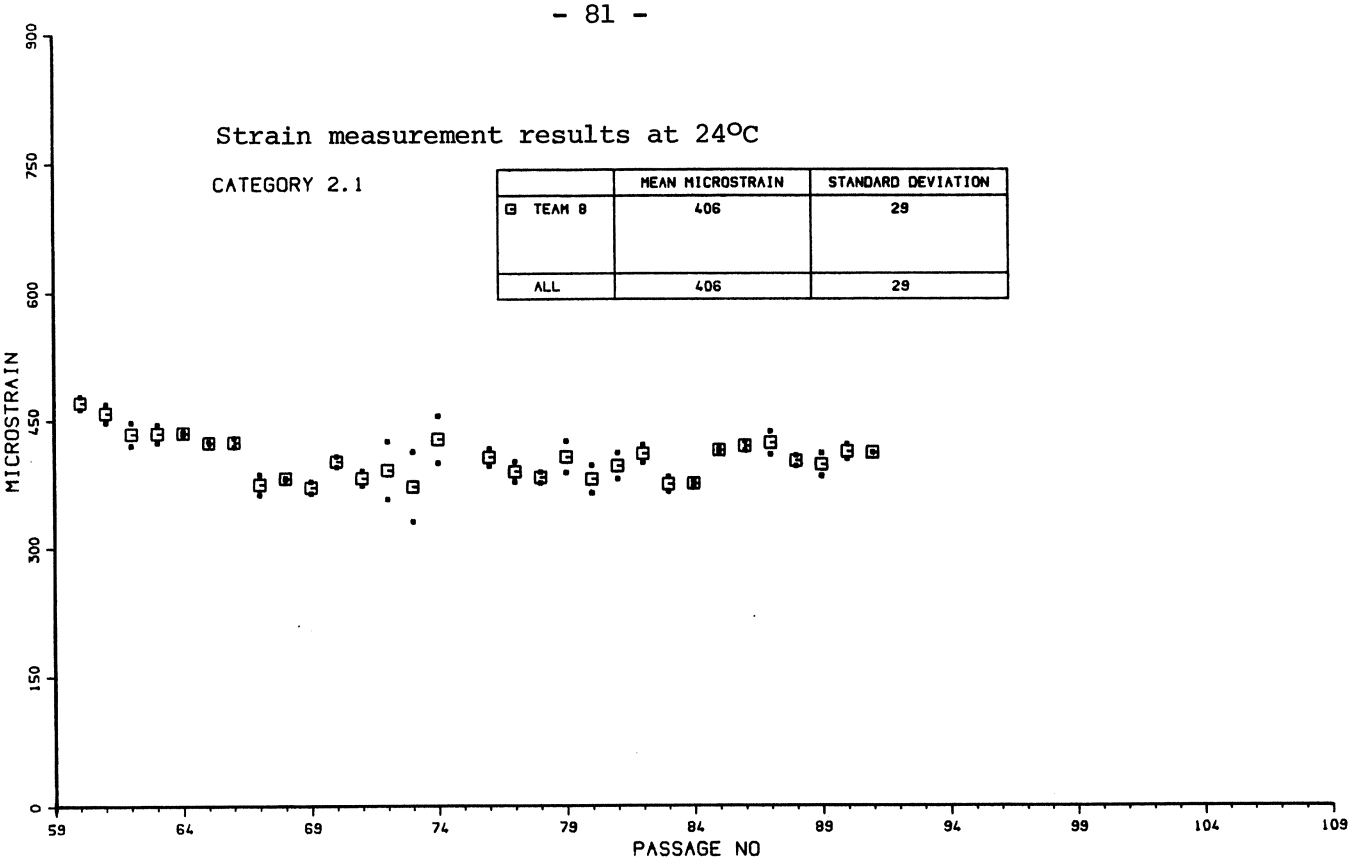


Figure VI.27 Variation of absolute maximum standardised strain with gauge category

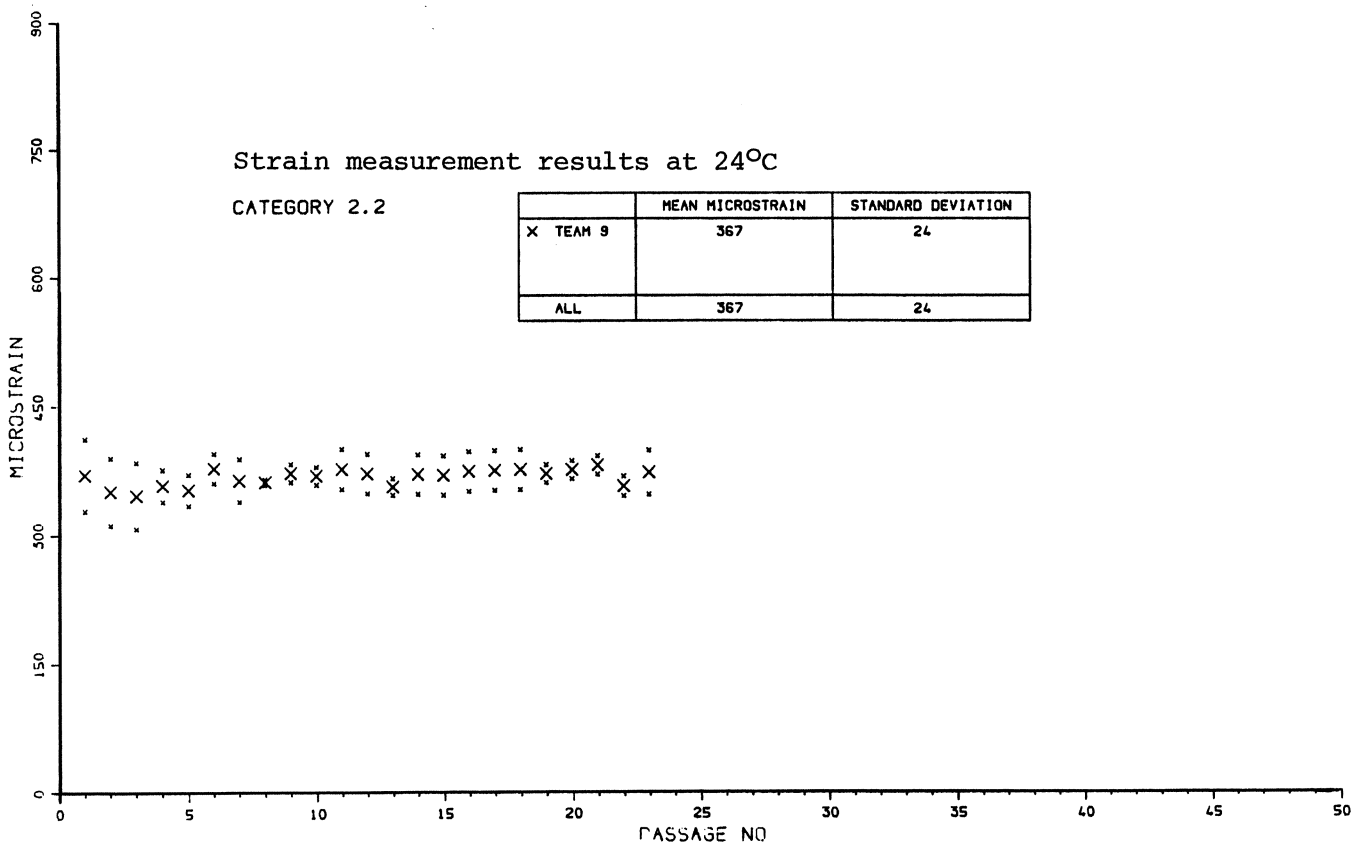


Figure VI.28 Variation of absolute maximum standardised strain with gauge category

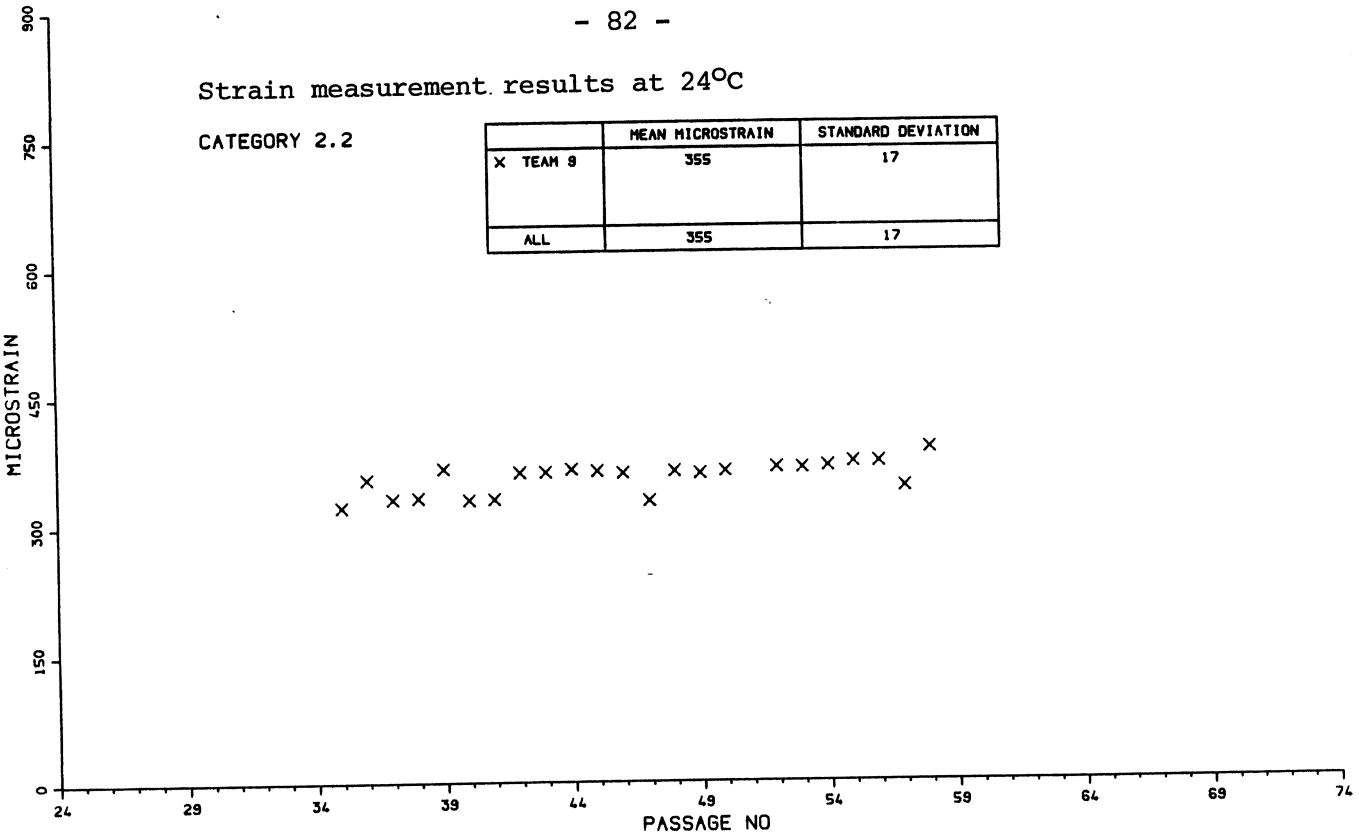


Figure VI.29 Variation of absolute maximum standardised strain with gauge category

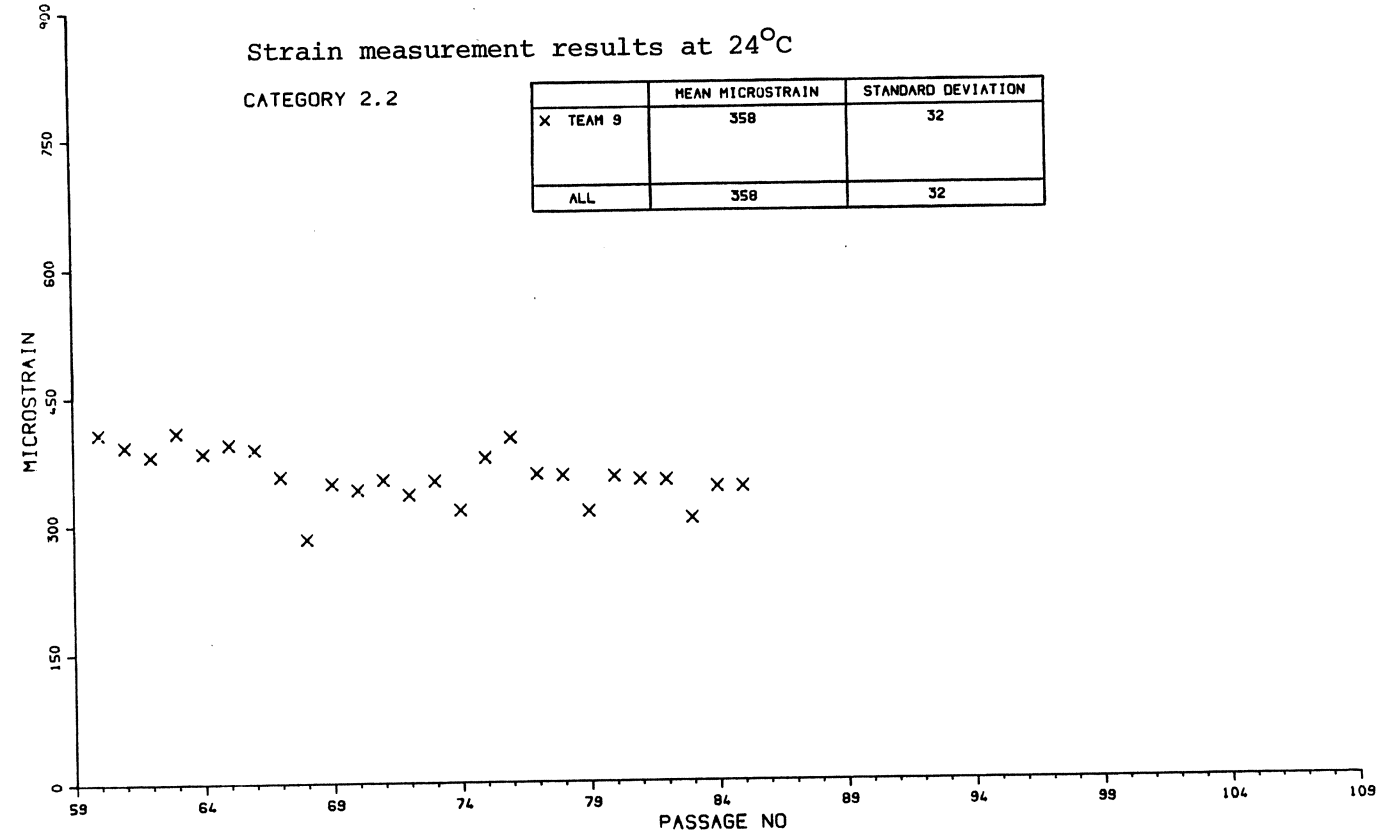


Figure VI.30 Variation of absolute maximum standardised strain with gauge category

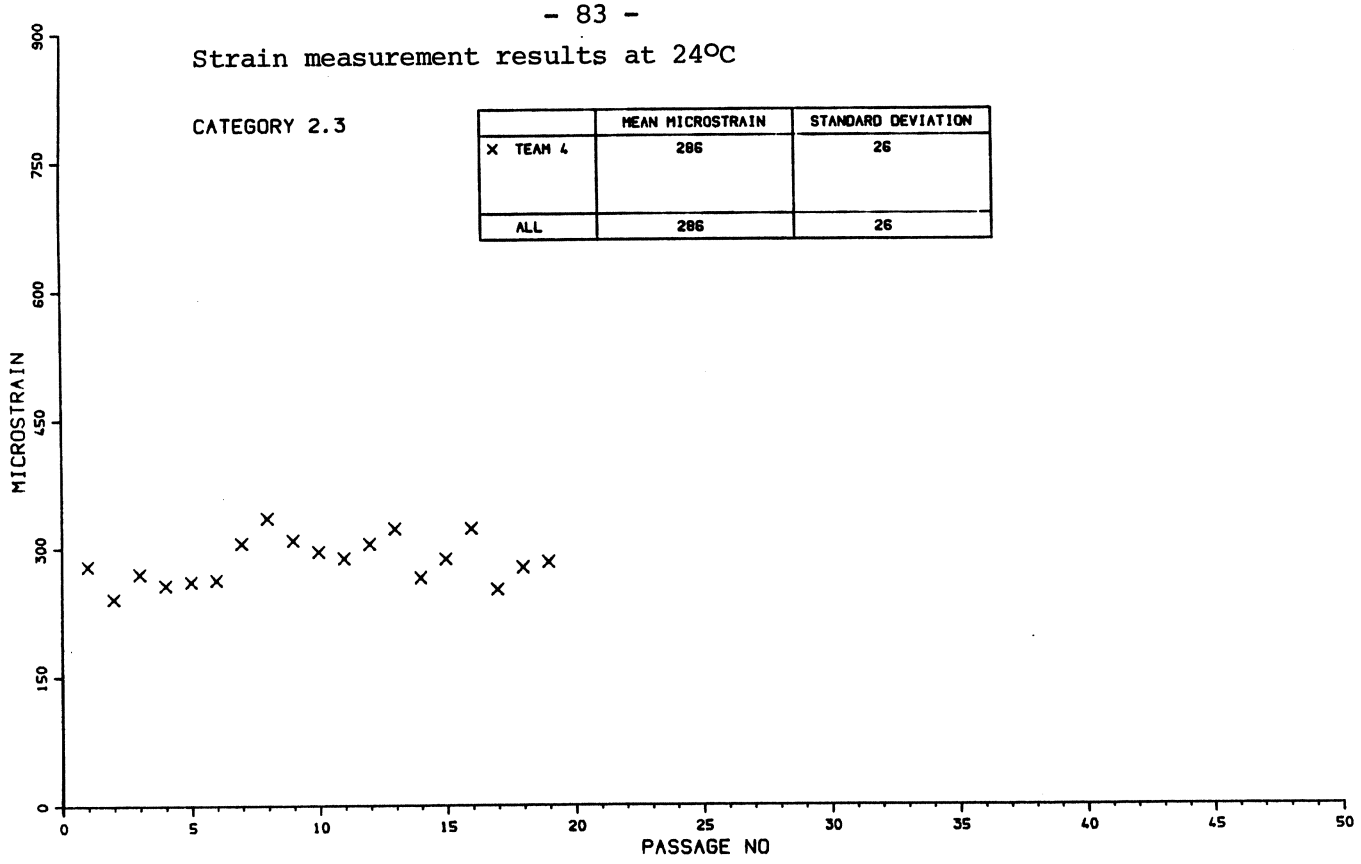


Figure VI.31 Variation of absolute maximum standardised strain with gauge category

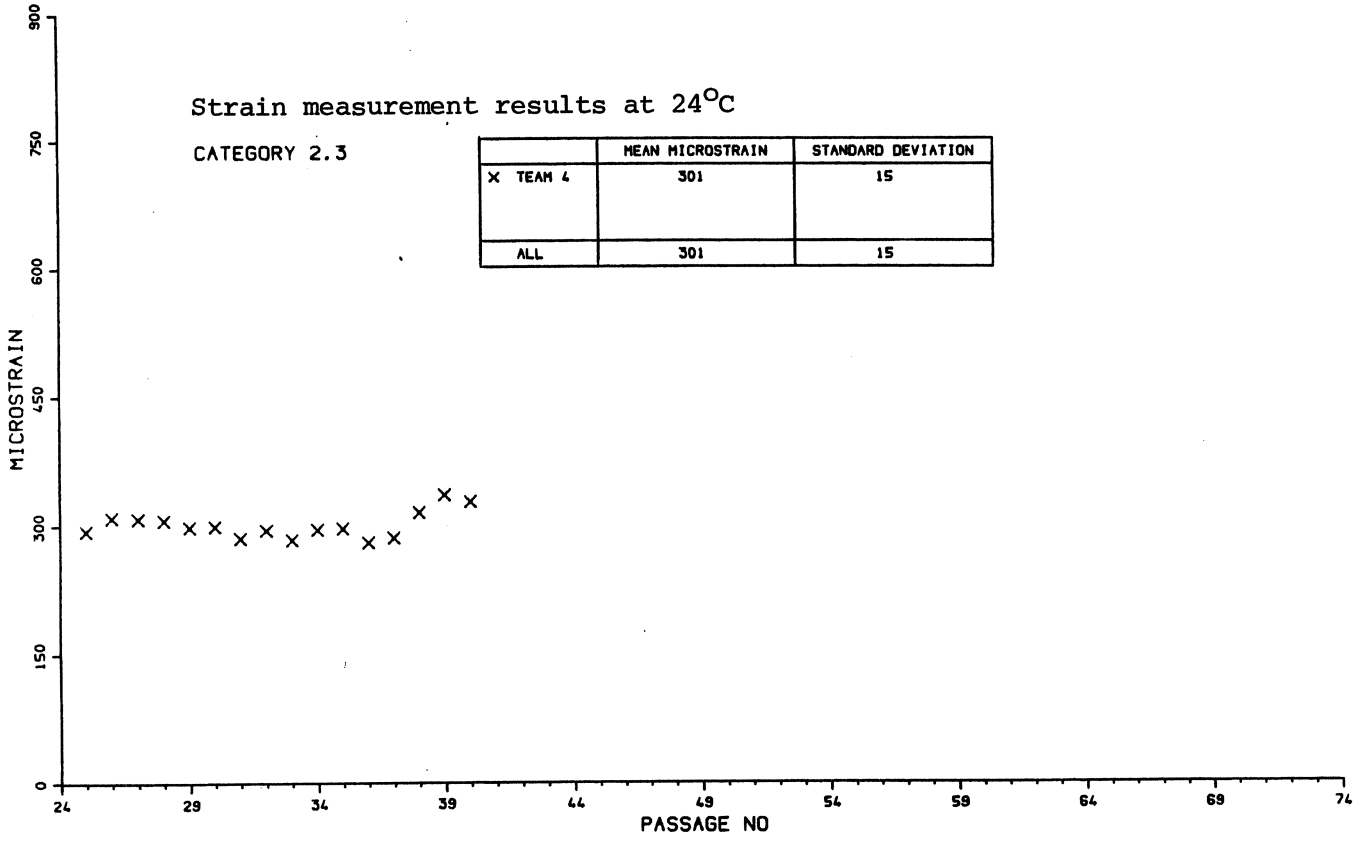


Figure VI.32 Variation of absolute maximum standardised strain with gauge category

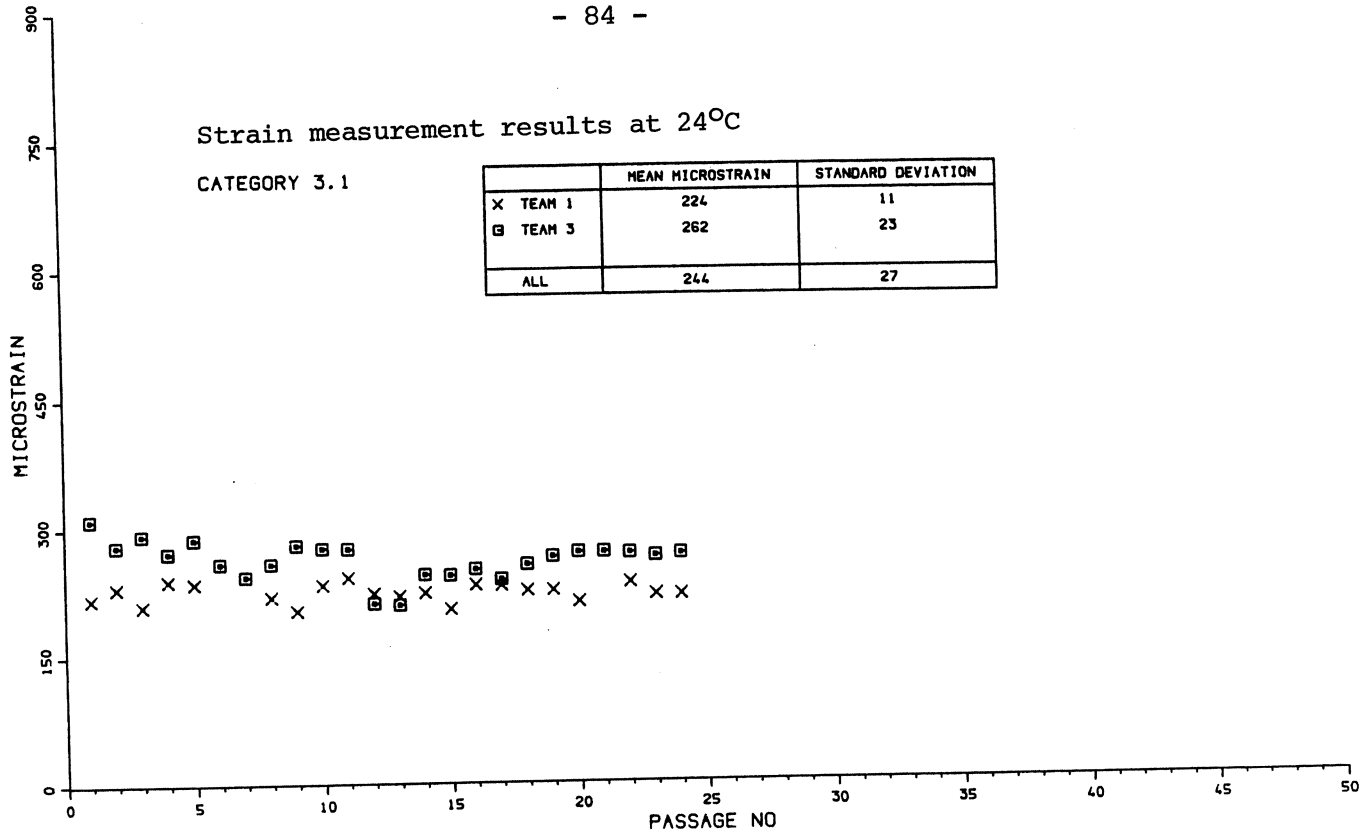


Figure VI.33 Variation of absolute maximum standardised strain with gauge category

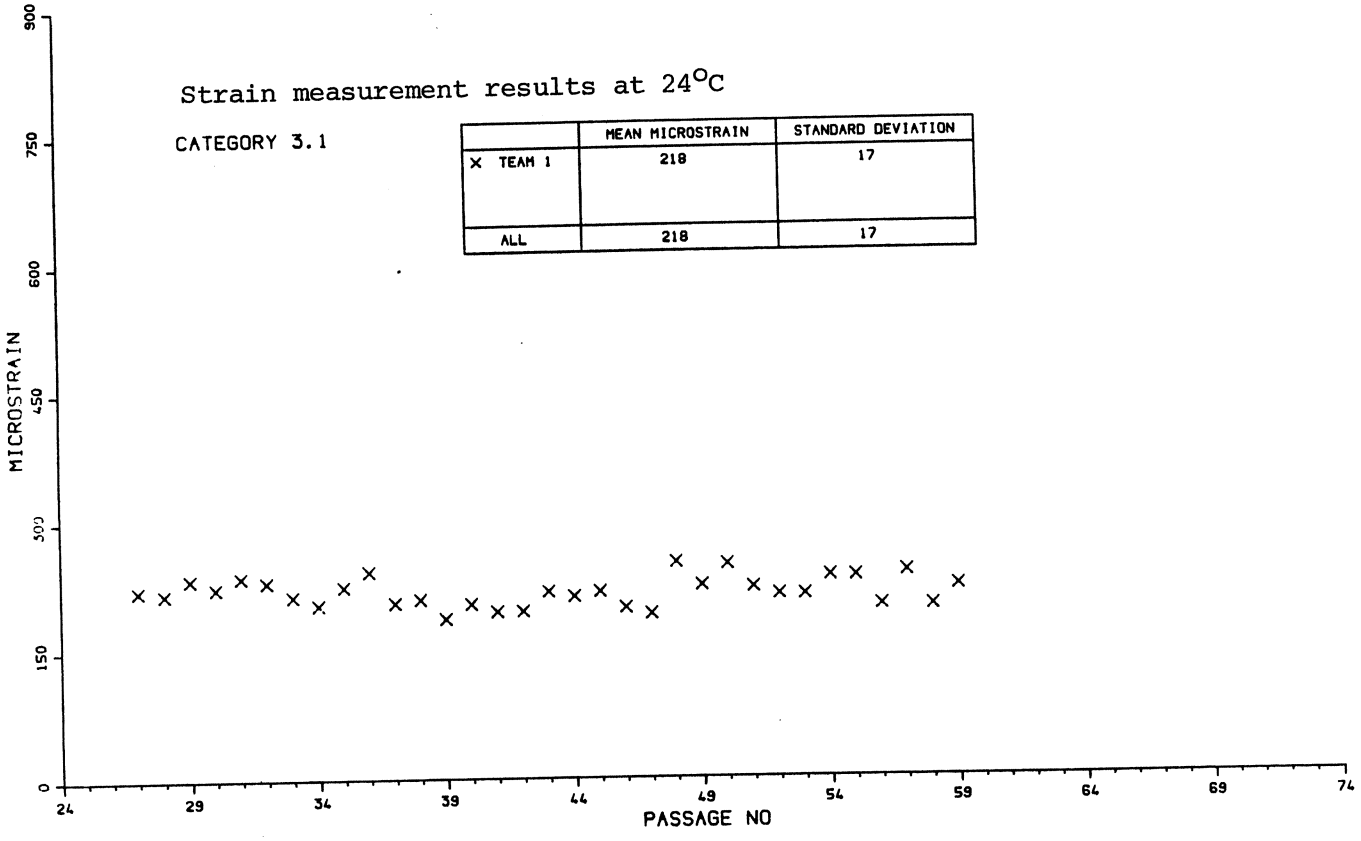


Figure VI.34 Variation of absolute maximum standardised strain with gauge category

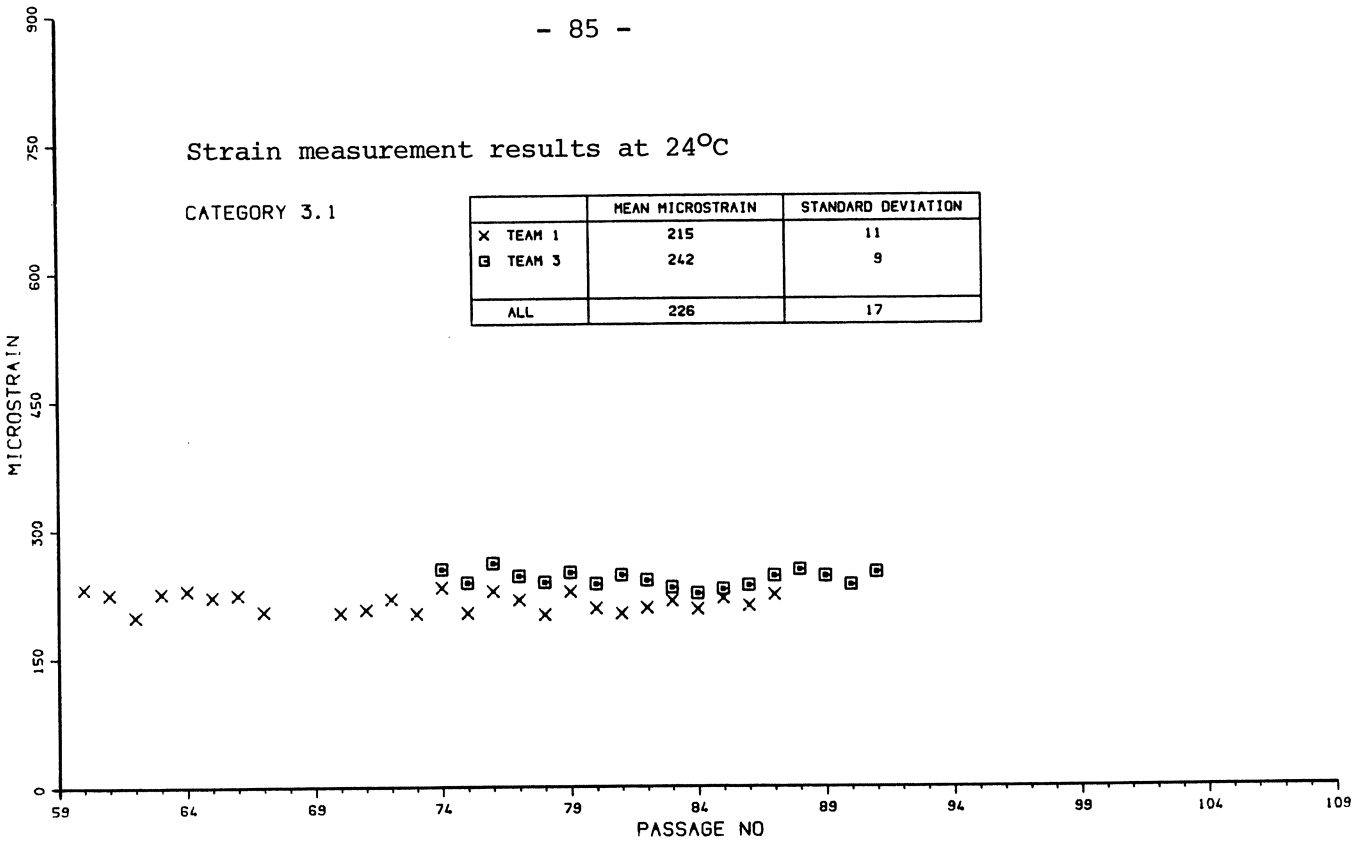


Figure VI.35 Variation of absolute maximum standardised strain with gauge category

CATEGORY	TEAM NO.	DAILY MEAN VALUES DAY 1	DAY 2	DAY 3	MEAN OF MAXIMUM DAY 1	DAY 2	DAY 3
1.1	3	267	242	243	294	258	254
	5	269	275	288	307	315	304
	7	314	290	300	335	322	320
1.2	2	164	274	261	164	273	261
	6	199	181	186	212	196	198
1.3	1	151	149	---	181	177	---
2.1	1	126	135	---	175	183	---
	8	325	328	357	379	391	387
2.2	9	270	227	247	357	337	343
2.3	4	246	238	---	266	275	---
3.1	1	135	128	138	212	202	208
	3	203	---	220	254	---	236

Figure VI.36 Standardised strains for each gauge category (24°C)

VI.3 DISCUSSION

The purpose of the coordinated campaign of measurements held at Nardò was to compare the results gathered under nominally identical conditions by the various techniques for strain measurement at present in use in different countries.

The analysis carried out so far demonstrates the extreme difficulty of making such a comparison, namely that the conditions of the testing are seldom identical for all the participating teams. The tables of Annex B 2 and B 3 for instance, show that the variation of characteristic pavement temperature is somewhat greater during the first day of the trial than the remaining two days. The highest pavement temperature attained also occurred during the first day, exceeding the maximum temperatures on the second and third days by some $4^{o}C$ and $7^{o}C$ respectively.

A second factor, adding to the difficulty of making comparisons, is the accuracy with which the loading vehicles were able to drive repeatedly over a fixed trafficking line. A change of drivers during the first day of the experiment contributed further to this difficulty, and, as has been stated earlier, some of the dispersion of results is brought about by the apparent inability of the loading vehicles to drive along the given line with sufficient accuracy. This may of course be an unrealistic demand on a purely manual system, the accuracy of which is certain to be poorer than the guided or automatic system likely to be found in other forms of full-scale testing.

Following standardization of the results to a single pavement temperature, the dispersion of results for some given groups of gauges is reduced, but the amount of the reduction varies according to the gauge type. If it is assumed that the standardization process works equally well for all gauges and all participating teams, then the residual dispersion of results and variation of the mean microstrain is a combination of both the inherent repeatability of the gauges and the transverse position of loading vehicles passing along the gauge line. From those results in which an attempt has been made to allow for the variation in transverse position of the vehicles (see Figures VI.17 to VI.35) it is clear that the standardized mean is changed only very little, but the dispersion of results is considerably reduced. This indicates that a significant part of the dispersion can be due to inaccurate vehicle positioning.

When the results are presented on the basis of the different gauge types used in the trials, some differences in performance become apparent. Thus, for example, when the mean of the standardized strain maxima generated by each loading vehicle is considered, the range of measured strain is from 181 μstrain to 357 μstrain. Theoretical calculations using program BISAR suggest that at $24^{o}C$, and making allowance for variations in the thickness of the bituminous pavement layer from 11.7 cm to 13.8 cm (as was observed in practice), the expected range of horizontal strains beneath the rear wheel of the vehicle at the bottom of the layer is 263 - 251 μstrain. It is known, however, that as a result of installation techniques, not all gauges were located precisely at the bottom of the layer. Further calculations show that a variation of 2 cm in the level at which a gauge is located can produce a reduction in strain to a value of 67 % of that which would occur at the true base of the layer, for temperatures between $18^{o}C$ and $32^{o}C$. The possible range of theoretical values of strain

measured at the bottom of the bituminous layer is therefore 168 - 263 µstrain. Figure VI.36 and VI.37 sets out category by category the mean daily values of strain, standardized to 24°C, together with the mean of the maximum strains recorded in each passage (thus minimising variations due to transverse positioning of the vehicles). Many of the results fall within the expected range, although there is a concentration of results towards the higher end.

Within a given category it is generally the case that where more than one group of gauges is being operated, the agreement between results from different groups is good. Only in category 2.1 does a substantial difference arise between the different users of this type of gauge, for example with different thickness of the glue.

Team number 1 operated groups of gauges in each of three different categories. The standardized means of maxima measured by each of these groups indicates a considerable degree of consistency (181, 175, 212 µstrain) even though these values are somewhat lower than the norm. Such consistency shows that the gauges are likely to be operating accurately and reliably, and because the mis-alignment of loading vehicles has already been taken into account in the presentation of these results some other explanation of the lower means must be sought.

Similarly, the results of team number 8 show a relatively low standard deviation, but a rather higher mean value than the remainder of the results, indicating that although the gauges themselves can be assumed to be working normally, an external factor, perhaps arising during installation or brought about by variations in pavement strength, material modulus or adhesion of the layers is responsible for the higher measurements.

The strain-pavement temperature relationships shown in Figures VI.2 to VI.10 were developed from all the data on strain and the measurements of temperature made by team 3. From laboratory tests on the materials used in the pavement construction, the moduli were established, and these were used as input values to program BISAR to investigate the theoretical influence of temperature on measured strains. The details of this are given elsewhere in this report, but in summary it was found that for the variation in bituminous layer thickness measured at Nardò the theoretical relationship between strain ε(µstrain), and pavement temperature T (°C) was

$$\varepsilon = 13.76*T - 64$$

The actual slopes of the strain-pavement temperature relationships vary widely about this theoretical figure, from 4.7 to a maximum of 32.1, and show no correlation with gauge group or geographical location on the site. When considered on the basis of gauge category however, as summarized in fig. VI.38, it is apparent that the lowest values of slope coefficient are associated with gauges of category 1.2 and that within each category the greatest variations of slope coefficient occur in categories 2.1 and 3.1. This could also show that the definition of the different categories is not always very successful.

Gauges of category 1.2 are known to be stiffer than other categories and this may account for their apparently lower temperature sensitivity, and, at least in the case of team 6 their generally lower but consistent results.

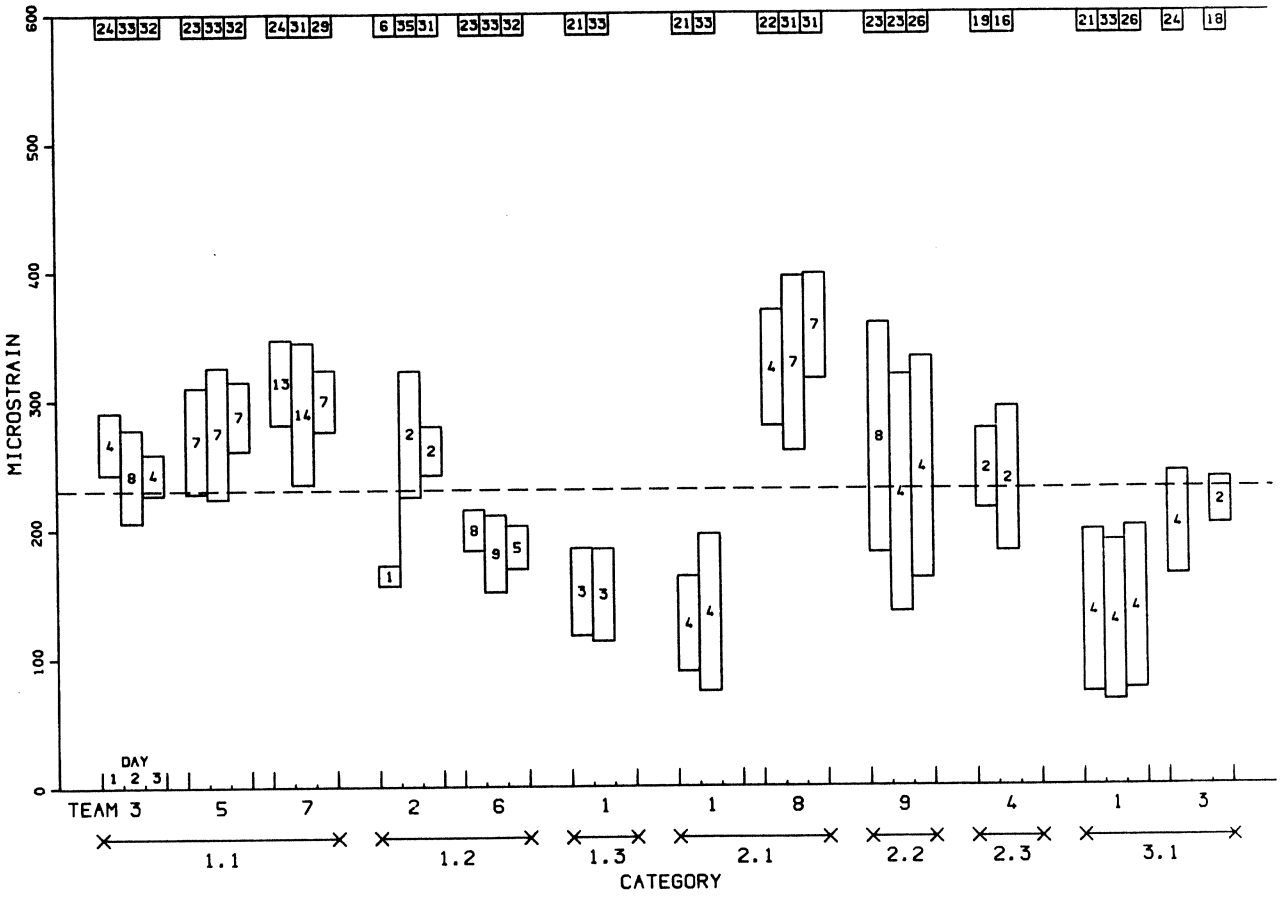


Figure VI.37 a Mean and standard deviation of strain measurement results at 24°C, all gauges, by day of measurement, team and gauge category

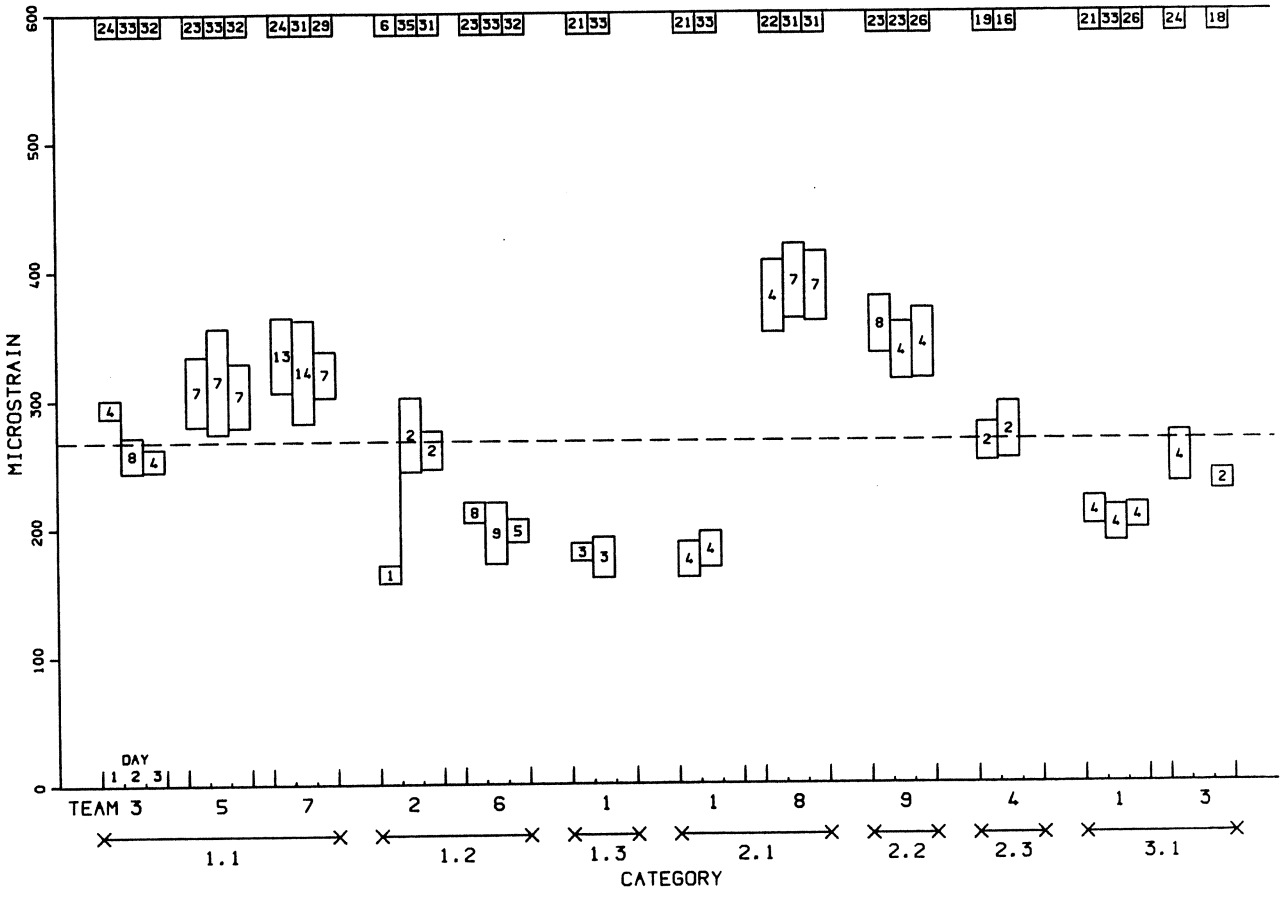


Figure VI.37 b Mean and standard deviation of maximum strains at 24°C, by day of measurement, team and gauge category

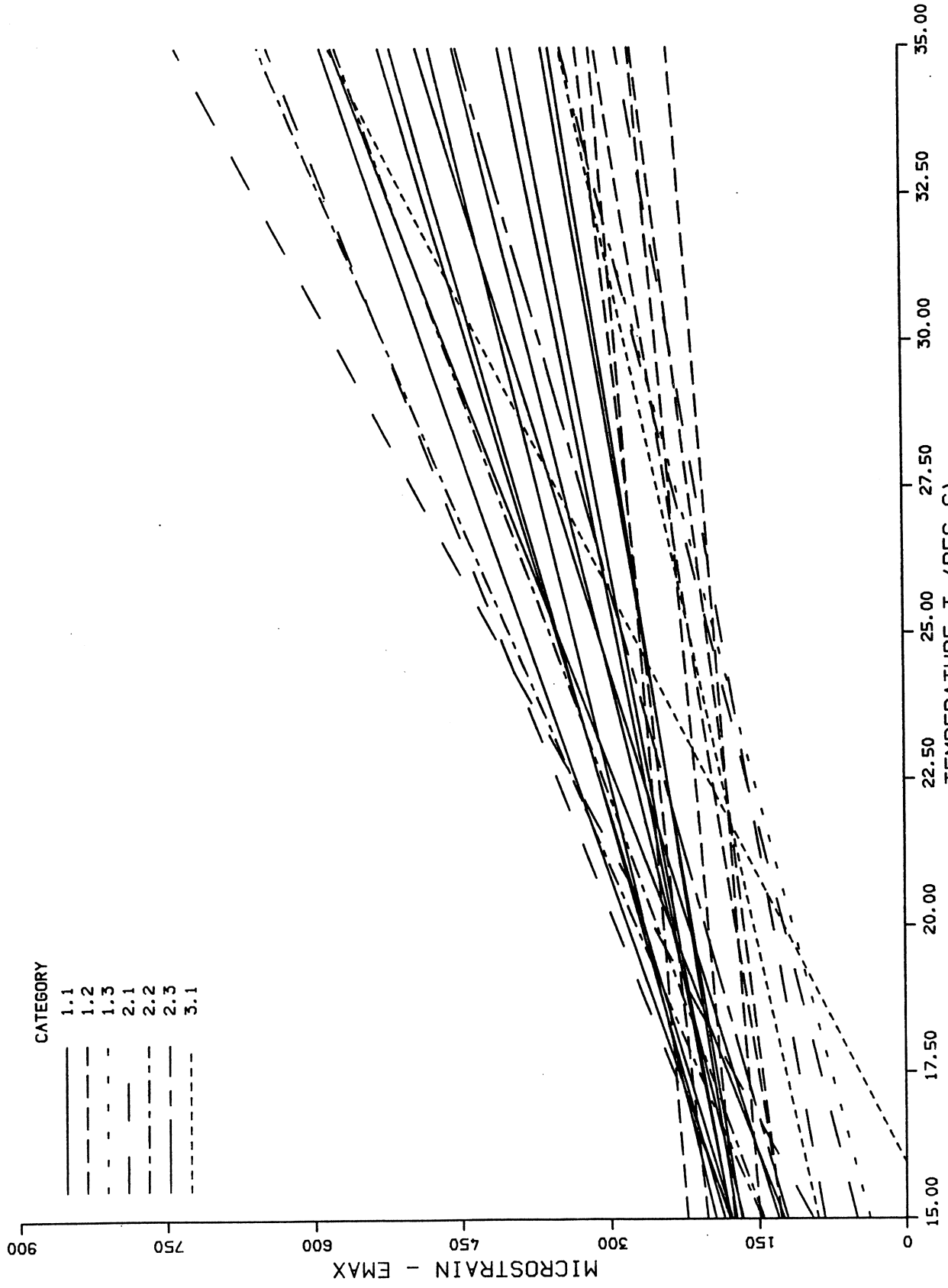


Figure VI.38 Relationships between strain and pavement temperature, by gauge category

The variability of gauges in categories 2.1 and 3.1 may be brought about by the fact that each category uses a coring technique for gauge installation after pavement construction with a different thickness of the glue. It is possible in certain cases that this method of installation impedes measurement of the true strain by introducing a third material (adhesive) to the pavement structure and by inhibiting intimate contact between the gauge and the mass of pavement material.

By contrast, the slope coefficients of gauges in category 1.1 (which has the largest number of operating gauges) are evenly and fairly closely distributed about the theoretical value, and the single groups in categories 1.3 and 2.3 also have slope values lying close to the theoretical value. The remaining two groups of gauges, in category 2.2, show a slope coefficient which is consistent but considerably higher than the theoretical value.

Chapter VII

INTERPRETATION

VII.1 SCOPE

In the previous chapter (Ch. VI) an attempt has been made to analyze the results of the strain measurements carried out by the various teams. Besides a series of valid conclusions, much emphasis has been given to the many difficulties which have hindered the work. The task of analyzing this common experiment in the field would not be complete without additional attempts to ascertain the validity of the results and to explain some of the causes which might have led to certain differences, that were encountered.

Among the various additional steps of analysis taken by different participants in the common tests three separate groups of approaches can be defined. On the one hand all of the variable parameters which have given great difficulties for the data analysis work described in the previous chapter have been the object of detailed studies with the purpose of quantifying their influence; the findings of these studies are briefly described in part VII.2.

On the other hand, the attempt to explain theoretically the results and their variability, i.e. though the determination of "theoretical" strain values with the use of an analytical pavement model and the characterization of pavement materials from the results of field or laboratory tests. Results from this type of work will be given in part VII.3. Finally, also the influence on the results deriving from the gauge construction has been studied, in particular the effects caused by the stiffness of the gauge and by the presence of glue. The results of these studies are reported in part VII.4.

In part VII.5 field data are adjusted on the basis of the findings about variable parameters described in part VII.2.

VII.2 INFLUENCE OF VARIABLE PARAMETERS

VII.2.1 Extent of the analysis

As it has already and repeatedly been pointed out in this report, in particular together with the analysis of the results in chapter VI, that many variable factors can have a lesser of greater influence on the measured strain values under load.

The differences which might arise from non-homogeneous material properties (quality and thickness of all pavement layers and the subgrade) have already been demonstrated indirectly by the results of dynamic testing of the pavement using either the Dynatest 8000 FWD equipment or the heavy vibrator of BAST (see Fig. IV.18, Chapter IV.4).

For other parameters intervening during the OECD common program at Nardò the theoretical influence has been calculated. Calculations done at BAST using the BISAR* pavement model (and considering the same type of pavement structure as also used in the studies mentioned in chapter VII.3) have shown in particular the influence on the calculated strain value of

- a change in temperature of the bituminous layers
- a difference in thickness of the bituminous layers
- the distance of the strain gauge from the bottom of the layer
- eccentric loading.

VII.2.2 Pavement model and basic input data

All of the calculations have been made with the use of the BISAR model (and assuming a rough interface) using a three-layer system with basically the following input data:

Layer Nr.	Material	Thickness [mm]	E [MPa]	ν -
1	Bituminous concrete	135[1,2]	3300[3,4]	0.35
2	Crushed stone base	170	250	0.45
3	Subgrade	∞	200	0.45

1) thicknesses of 120 and 135 mm have been used for the study of the influence of temperature and distance of the strain gauge from the bottom

2) 7 different thicknesses between 117 and 135 mm have been analyzed for the influence of layer thickness

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* BISAR: D.L. De Jong, M.G.F. Peutz, A.R. Korswagen, "Computer Program BISAR", SHELL Laboratorium, Amsterdam, 1973.

3) moduli between 8000 (at 15 °C) and 1300 (at 32 °C) MPa have been used for the study of the influence of temperature. In this particular case also the condition of absence of friction between the bituminous layers and the crushed stone base was investigated.

4) in the analysis of the influence of the distance of the strain gauge from the bottom of the layer two cases have been considered, i.e. 18 °C (6500 MPa) and 32 °C (1300 MPa).

Load:	Front wheel	27.5 kN	R = 110 mm
	Rear wheel	2 x 29.0 kN	R = 107 mm

Results are normally given for the load axis, in the case of the effect of eccentric loading for all positions.

As will also be mentioned in part VII.3, the three-layer model chosen here might not be the most appropriate characterization of the structure of the test pavement at Nardò. The relative values derived from these calculations should, nevertheless, provide an acceptably precise estimation.

VII.2.3 Influence of temperature

Figure VII.1 indicates the influence of varying temperature (and modulus) of the bituminous concrete for the load case of the rear wheel.

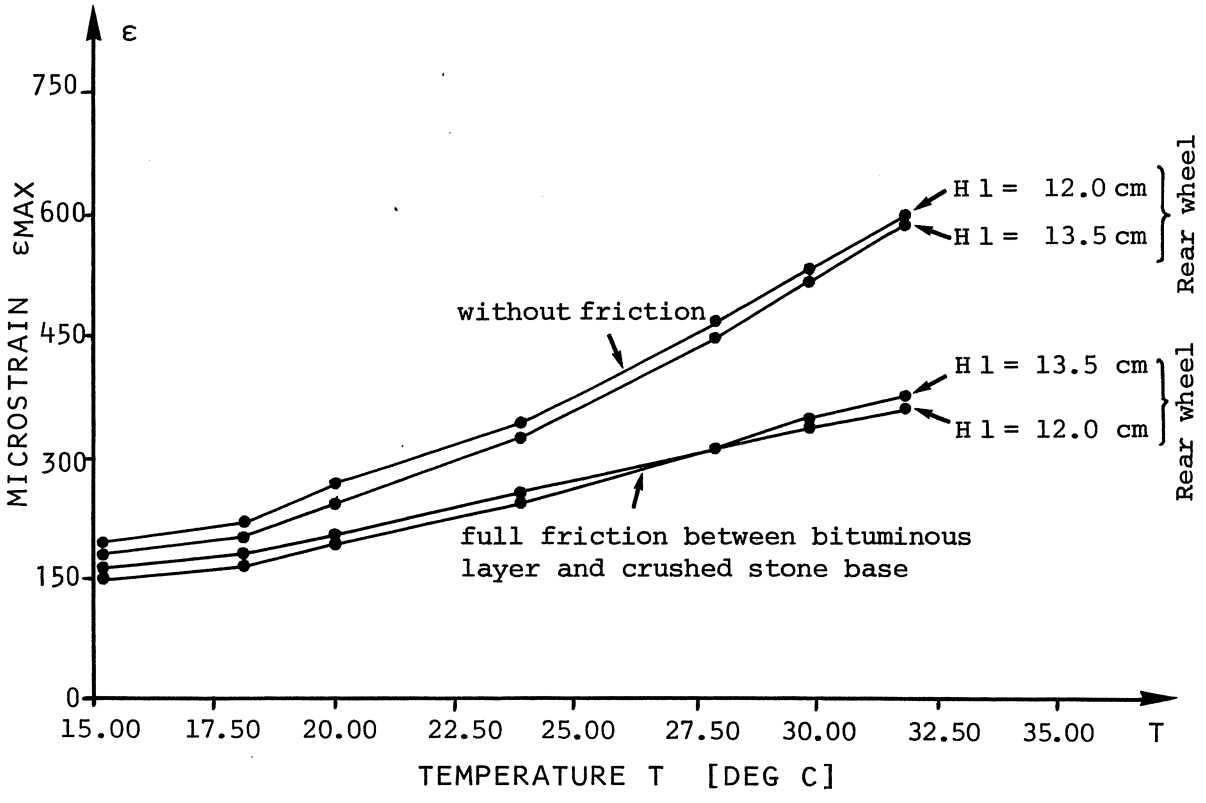

Fig. VII.1 Influence of temperature of the bituminous layers on strain values

It can be seen from the figure that the influence of temperature is extremely important. In the range of temperature values measured during the experiment at Nardò, a temperature change of 5 °C can lead to a difference of almost 50 % in the measured strain. For the calculation of the strain-temperature relationship the case of absence of friction between the bituminous layers and the crushed stone base was also investigated. The corresponding steeper curve is also to be seen in Fig. VII.1.

VII.2.4 Influence of the thickness of the bituminous layer

The results of the analysis are indicated in the following figure VII.2:

	STRAIN ε xx	
H1	FRONT WHEEL	REAR WHEEL
117	227	263
120	221	263
122	217	259
125	211	257
130	202	255
135	193	252
138	188	251
[mm]	$[10^{-6}]$	

Three Layer system: (T_{ref} = + 24°C)

E1 = 3300 H1 see above ν1 = 0.35
E2 = 250 H2 = 170 ν2 = 0.45
E3 = 200 - ν3 = 0.45

[MN/m2] [mm] [1]

Figure VII.2 Influence of layer thickness

The results show different magnitudes of influence for the load cases of the front and the rear wheels. In the latter cases, with higher absolute values, the changes in horizontal strain amount to only 5 % when the thickness of layer changes by 18 %. The influence of layer thickness can thus be considered as of rather minor importance.

VII.2.5 Influence of the distance of the strain gauge from the bottom of the bituminous layer

In analytical pavement design systems it is customary to consider tensile strain at the bottom of bituminous layers as one of the design criteria (fatigue). It is thus in the interest of all experimental work

on pavements to measure strain at this location. However, it is not always possible, for many reasons, to place the active part of a gauge just at this position; some protective measure like an embeddment for the gauge of the gauge supporting element itself can lead to a somewhat "higher elevation" of the position of the gauge in relation to the bottom of the bituminous layer. The differences from the nominal position have been indicated in chapter III. The results of the comparison of calculated and measured ε-values in chapter VII.3 for those teams with a ratio $\varepsilon_m/\varepsilon_c$ near to 1.0 (the mean value of the ratio for those teams being > 1.0) also indicates a tendency to have an "increased elevation".

The results of the analysis of this influence are given in the following figure VII.3.

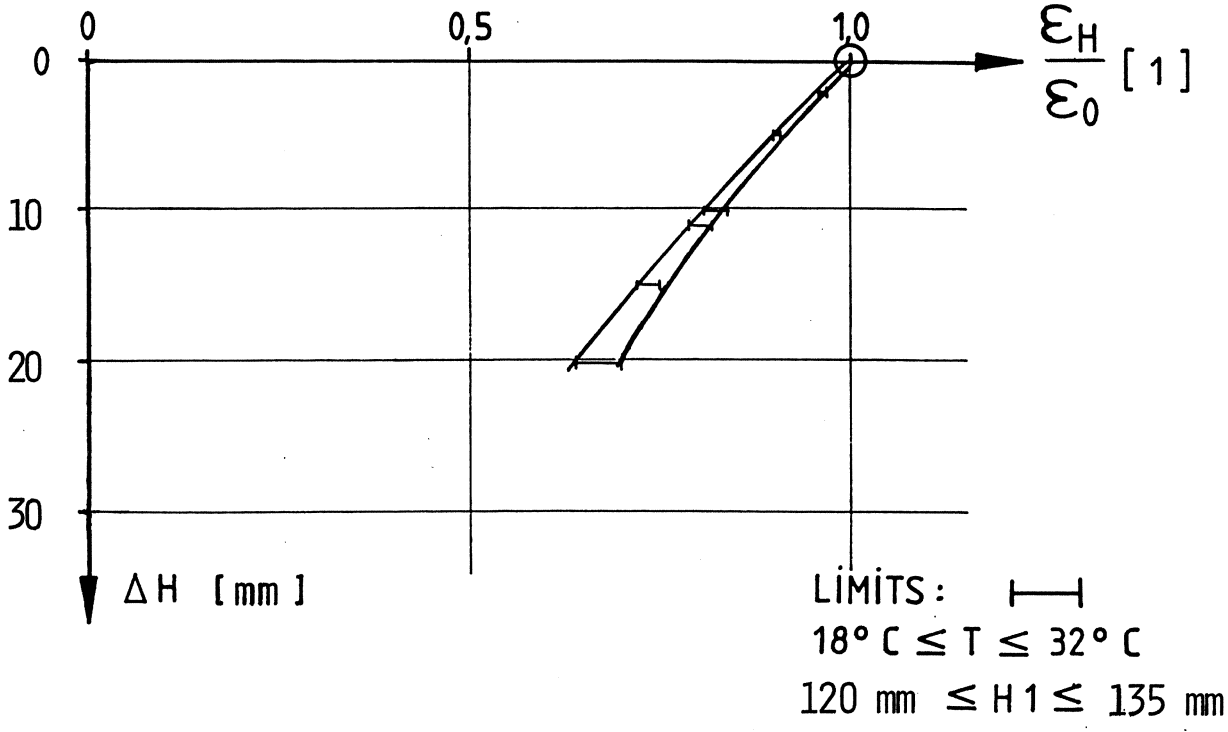

Fig. VII.3 Influence of the distance of a strain gauge from the bottom of the bituminous layer (ε_o: strain at bottom of layer, ε_H: strain at a distance ΔH above the bottom of the layer)

These results show that the influence is not negligible at all, with strain differences of 10 % for as little as 5 mm of distance and up to 30 % for 20 mm of distance.

VII.2.6 Influence of eccentric load

Much has also been said in the previous Chapter about the precision of the vehicle drivers in the test to hit the center of the positioning line of the strain gauges, so as to get a possibly high number of "center hits" and hence really maximum values on the gauges. This is also dependent on the geometrical characteristics as described in chapter V.

Fig. VII.4 shows the influence lines for tensile strain at the bottom of the bituminous layer in the direction of traffic. As can be seen, the curve for the rear wheel, for which the corresponding strain values were analyzed, is quite flat over both tyres and including the portion in between. However, strain values begin to decrease at the outer edge already under the tyre. A value of only 50 % of the maximum can be calculated at a distance of 50 mm from the outer edge of the tyre. The results of these calculations show the great importance to have precise "placement" of the gauge position.

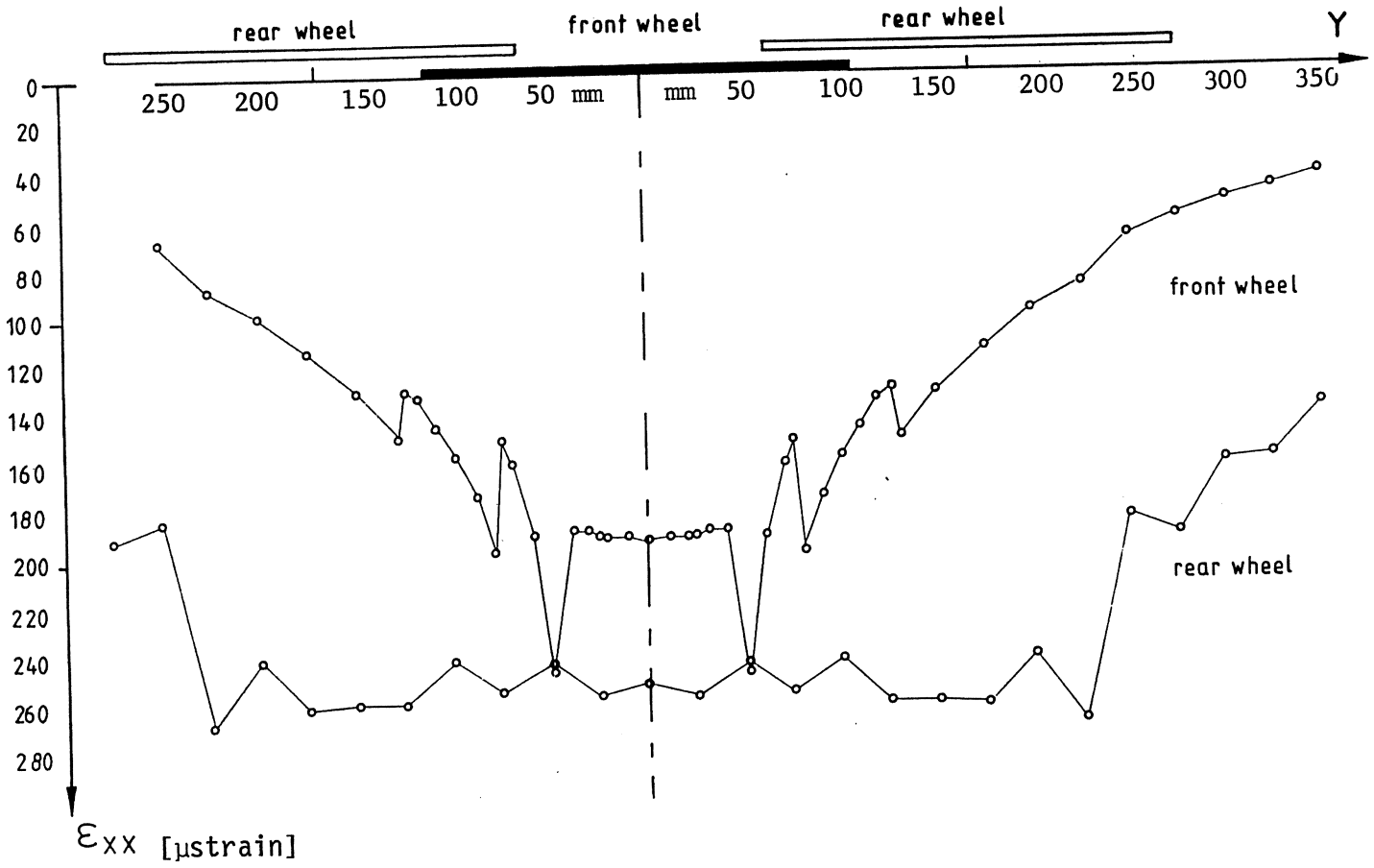

Fig. VII.4 Horizontal tensile strain at the bottom of the bituminous layer as a function of the lateral position under the wheels

VII.3 CALCULATION OF STRAIN VALUES

VII.3.1 Comparison of measured and calculated strains using FWD results

The Method of Equivalent Thicknesses (MET), (which is also used by ELMOD), was used to calculate the strains in the bituminous layers for a dual wheel for the moduli given in Fig. IV.19 and IV.20 of chapter IV.4.2. The dual wheel from trucks A and C were simplified as two circular loads with a radius of 107 mm and a uniformly distributed load of 0.8 MPa. The distance between the centers of the two loads was 340 mm.

The loading time of the FWD (used to determine the moduli) is approximately 25 ms, corresponding to a velocity of 60 - 70 km/h. The actual velocity of the trucks was only about 30 km/h. To allow for this difference in loading time the moduli of the bituminous layers were reduced by 25 %. This reduction was estimated from the relationship between modulus and loading frequency obtained at the Bundesanstalt für Strassenwesen on sample No. x 13, from the test road. A Poisson's ratio of 0.35 was assumed for all layers.

The calculated strains were compared with some of the measured strains. For the moduli measured on the afternoon of April 11 the passages 85 - 89 were selected. These passages were executed immediately before the FWD testing. For the moduli from the morning of April 12 the passages 60 - 63 were selected. These passages were executed during the morning of April 11, when the temperature conditions were similar to those of the morning of April 12. The measured value is the mean of the maximum value from each group of instruments under each passage of either truck A or truck C.

The calculated strains ε_c, the measured strain ε_m, and the ratio of measured to calculated strain, $\varepsilon_m/\varepsilon_c$, are given in Fig. VII.5 and Fig. VII.6. On the morning of April 12 a range of moduli was determined at each test site. In the table are given the maximum and the minimum of the strains calculated from these moduli. For teams No. 1 and 2 no moduli were determined on April 12. The number given in parenthesis for teams no. 1 and 2 have the same ratio to the mean values of the strains for teams 2 to 8 as teams no. 1 and 2 had on April 11.

Fig. VII.5

Calculated strains compared to "mean maximum" strains ε_c from moduli determined April 11, pavement temperature 23.2 °C, ε_m from passages 85 - 89 (trucks A + C)

* from passages 35 - 40

Team	ε_c	ε_m	$\varepsilon_m/\varepsilon_c$
1	248	219	0.88
2	221	278	1.26
3	244	249	1.02
4	310	361*	1.16
5	293	318	1.09
6	317	201	0.63
7	291	326	1.12
8	247	388	1.57
9	281	273	0.97

Fig. VII.6

Calculated strains compared to "mean maximum" strains ε_c from moduli determined April 12, pavement temperature 15.5 °C, ε_m from passages 60 - 63 (trucks A + C)

* from passages 26 - 29

Team	ε_c	ε_m	$\varepsilon_m/\varepsilon_c$
1	(206-224)	140	0.62-0.68
2	(184-200)	225	1.12-1.22
3	200-225	208	0.92-1.04
4	268-282	236*	0.84-0.88
5	274-286	215	0.75-0.78
6	250-261	162	0.62-0.65
7	224-251	240	0.96-1.07
8	202-245	263	1.07-1.30
9	228-242	254	1.05-1.11

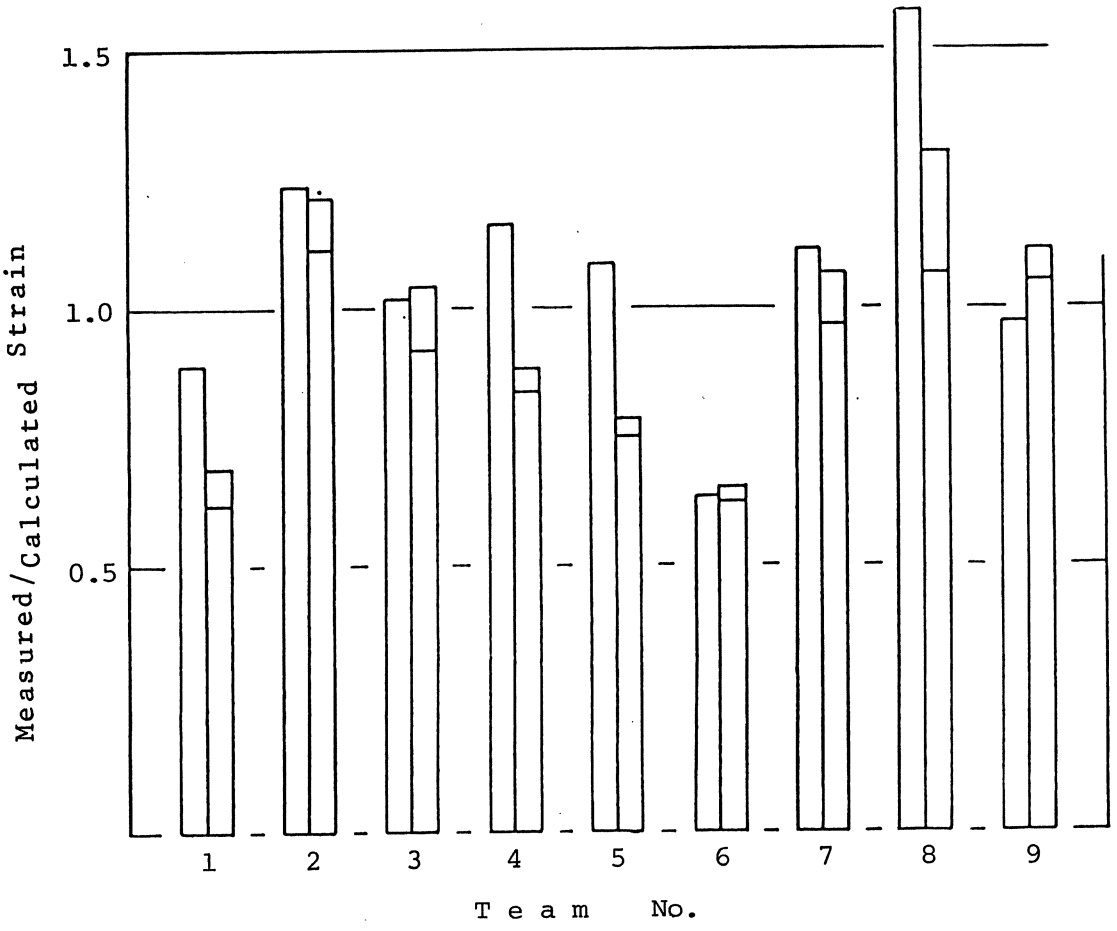

Fig. VII.7 Ratio of measured to calculated strain (from FWD testing)
First column: April 11, second column: April 12

This set of comparisons between measured and calculated strains has been done for only a few cases and is merely a spot check. Discrepancies of plus minus 20 % or more between measured and calculated values could therefore easily be due to the natural variations or random errors. The agreement found between measurements and theory thus appears extremly encouraging.

VII.3.2 Strain calculations using moduli of the bituminous layers determined in the laboratory

Intensive laboratory tests on cores taken from the Nardò pavement have been carried out by CRR in Belgium and BAST in Germany (see also Chapter IV.3). In both cases these moduli have also been used for calculating strains with two different pavement models, where each one of these considered the pavement as a three layer system. This means quite a substantial difference for the layer system used for calculations on the basis of FWD tests (see chapter IV.4.1.2 and VII.3.1) where a 4-layer system is the basis; layer no. 3 being a granular fill on top of the subgrade which itself, as layer no. 4 is considered as indefinitely stiff. Differences in the results deriving from the two pavement models should, therefore, not be surprising.

The comparison of values from calculations by CRR (using the program CRR-MTC) and BAST (using the program BISAR) in a similar layered system is thus primaily meant to compare both pavement model programs. The main difference between the two systems is the subdivision of the bituminous concrete in two different layers, as they in fact have been placed, in the Belgian pavement model (see Fig. VII.8).

Pavement Model	Temp.	E- CRR (MPa)	E- BAST (MPa)	ν
Surface layer 50 mm Binder layer 80 mm	15°C	8063 12500	8000	0.35
Surface layer 50 mm Binder layer 80 mm	24°C	3225 5000	3300	0.35
Surface layer 50 mm Binder layer 80 mm	35°C	645 1000	1000	0.35
Crushed stone base 170 mm	-	250	250	0.45
Subgrade	-	200	200	0.45

Fig. VII.8 Assumption of layer moduli for theoretical calculations

The results of strain calculations under the centre of the rear wheel using both methods are the following:

Temperature	15 °C	24 °C	35 °C
CRR	ε = 125 µstrain	ε = 218 µstrain	ε = 429 µstrain
BAST	ε = 150 µstrain	ε = 252 µstrain	ε = 426 µstrain

The differences are due to the choice of different moduli and test frequencies (15 Hz for the CRR-moduli, 8 Hz for the BAST-moduli). Calculations by the CRR-MTC methods using the moduli adopted by BAST lead to almost exactly the same results. It thus follows that both methods of calculating strains are comparable.

VII.4 STIFFNESS OF THE MEASURING SYSTEMS

VII.4.1 Strain gauges

All of the strain gauges used have a stiffness value which influences the result of the measurement. Such an effect is particularly important for the H-type gauges (Group 1), which have anchor bars mounted at each end to ensure that the strain in the gauge is the same as the strain in the bituminous layers. A certain compressive stress is therefore exerted on the bituminous material between the anchors, resulting in a compression of this material and thus in the gauge measuring a smaller strain in the bituminous layers than the strain if the gauge had not been there.

How large this error will be is extremely difficult to evaluate, but a rough estimate of the importance of the stiffness of the gauge can be obtained by assuming no contact between the gauge and the bituminous material, and that the stress created by the anchors is evenly distributed over the cross section of the anchors.

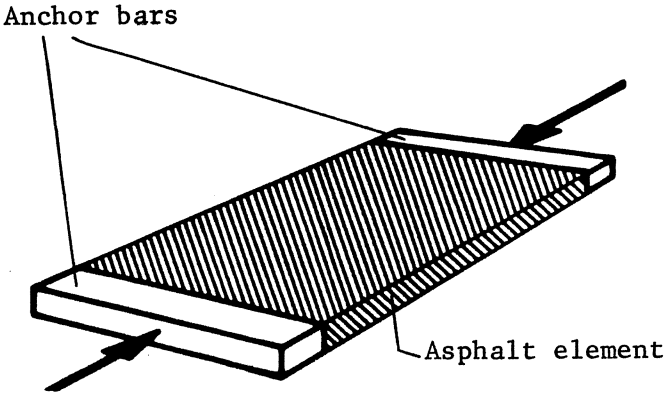

Fig. VII.9

Schematic model for the calculation of the error due to stiffness of the gauge

With these simplifications the errors have been calculated for the two following cases:

Case 1

Modulus of the bituminous layers 3870 MPa, temperature 23.2 °C
mean measured strain 270 microstrain

Case 2

Modulus of the bituminous layers 5770 MPa, temperature 15.5 °C
mean measured strain 245 microstrain

Team no.	Gauge	type	Total stress on bituminous material element		Compressive strain in bituminous material element	
			Case 1	Case 2	Case 1 %	Case 2 %
2	1.2	Aluminium	57 N	52 N	28 µstr.10	18 µstr. 7
3	1.1	Kyowa	51 N	46 N	22 µstr. 8	14 µstr. 6
5	1.1	Kyowa	51 N	46 N	21 µstr. 8	13 µstr. 5
6	1.2	Aluminium	151 N	137 N	56 µstr.21	35 µstr. 14
7	1.1	Kyowa	51 N	46 N	18 µstr. 7	11 µstr. 4

Fig. VII.10 Calculated errors for different H-type gauges

It is interesting to notice that the percentage error increases with increasing temperature (decreasing modulus of the bituminous layers). The results also show that all these systems (H-type gauges) are relatively rigid and that type 1.2 of team no. 6 in particular leads to a non -negligible decrease in the measured value of deformation.

Also the slopes in the strain-temperature relationship are much flatter for stiffer gauges.

VII.4.2 Cores

The main advantage of the gauges of group 2.1, team no. 8 and of group 3.1 is the possibility to place them into already existing pavements. However, the reinsertion of the core with the gauge requires a filling of the space between the core and the bore-hole. This space is very narrow (0.35 mm) in the case of team no. 8 which uses a specimen prepared in the laboratory with the exact dimensions of the hole (162 mm). The space, on the contrary, is more important (5 mm) for teams no. 1 and 3 (using 100 mm cores). The filling of the space with epoxy resin thus influences the measurement of the deformation through a local increase of the stiffness of the pavement.

VII.5 ADJUSTMENT OF FIELD DATA

Another way to find a valid interpretation of the results of the field experiment is obtained by applying the findings of the previous sub-chapters to the field data, i.e. the summary presentation of data by team and gauge type as shown in fig. VI.37. In this figure mean values and standard deviations, corrected to a reference temperature of 24 °C, are indicated. With the exception of the results of the first day for team no. 2, gauge type 1.2 (an error in the data acquisition system may likely be the cause of the discontinuity) the results are fairly constant over the three days regardless of actually different temperature conditions (see Fig. V.8). Before further conclusions can be drawn it is, however, necessary to correct the values at least by those factors which are known: the thickness of the layers (Fig. IV.2) and the exact position of the gauge in the layers (Fig. III.11), using the values indicated in Chapter VII.2, as indicated in Figure VII.11. The general picture of the results, shown in fig. VII.12, confirms basically those obtained in the approach previously described, with the exception of gauge type 2.2 of team no. 9, which now also becomes distinctly different. The range of ± 20 % about the mean value of all adjusted data (which do not consider variations in bearing capacity and material quality) also covers the range of calculated values.

The strain gauges showing the best agreement with the general mean value and calculated results are the following:

- type 1.1, as used by teams no. 3, 5 and 7
- type 1.2, as used by team no. 2
- type 2.3, as used by team no. 4
- type 3.1, as used by team no. 3.

Two gauges lead to values of about 150 % of the general mean

- type 2.1, as used by team no. 8
- type 2.2, as used by team no. 9

Four gauges lead to values 30 to 40 % lower than the general mean

- type 1.2, as used by team no. 6
- type 1.3, as used by team no. 1
- type 2.1, as used by team no. 1
- type 3.1, as used by team no. 1

Gauge type	team no.	mean of maxima at 24°C		ΔH mm	corr. ΔH %	corr ΔH abs.	H mm	corr.	corr. value
1.1	3	294 258 254	269	2	+ 4 %	+ 11	122	- 4	276
	5	307 315 304	309	2	+ 4 %	+ 12	118	- 7	314
	7	335 322 320	326	2	+ 4 %	+ 13	128	-	339
1.2	2	164 273 261	267	-	-	-	124	- 4	263
	6	212 196 198	202	4	+ 8 %	+ 16	120	- 5	213
1.3	1	181 177	179	-	-	-	127	- 1	178
2.1	1	175 183	179	-	-	-	127	- 1	178
	8	379 391 387	386	5	+ 10 %	+ 39	134	+ 3	428
2.2	9	357 337 343	346	15	+ 25 %	+ 86	134	+ 3	435
2.3	4	266 275	271	6	+ 12 %	+ 33	120	- 5	299
3.1	1	212 202 208	207	-	-	-	127	- 1	206
	3	254 236	245	11	+ 20 %	+ 49	122	- 4	290

Figure VII.11 Adjustment of 24°C-mean of maxima for ΔH (distance from bottom of layer) and H (layer thickness)

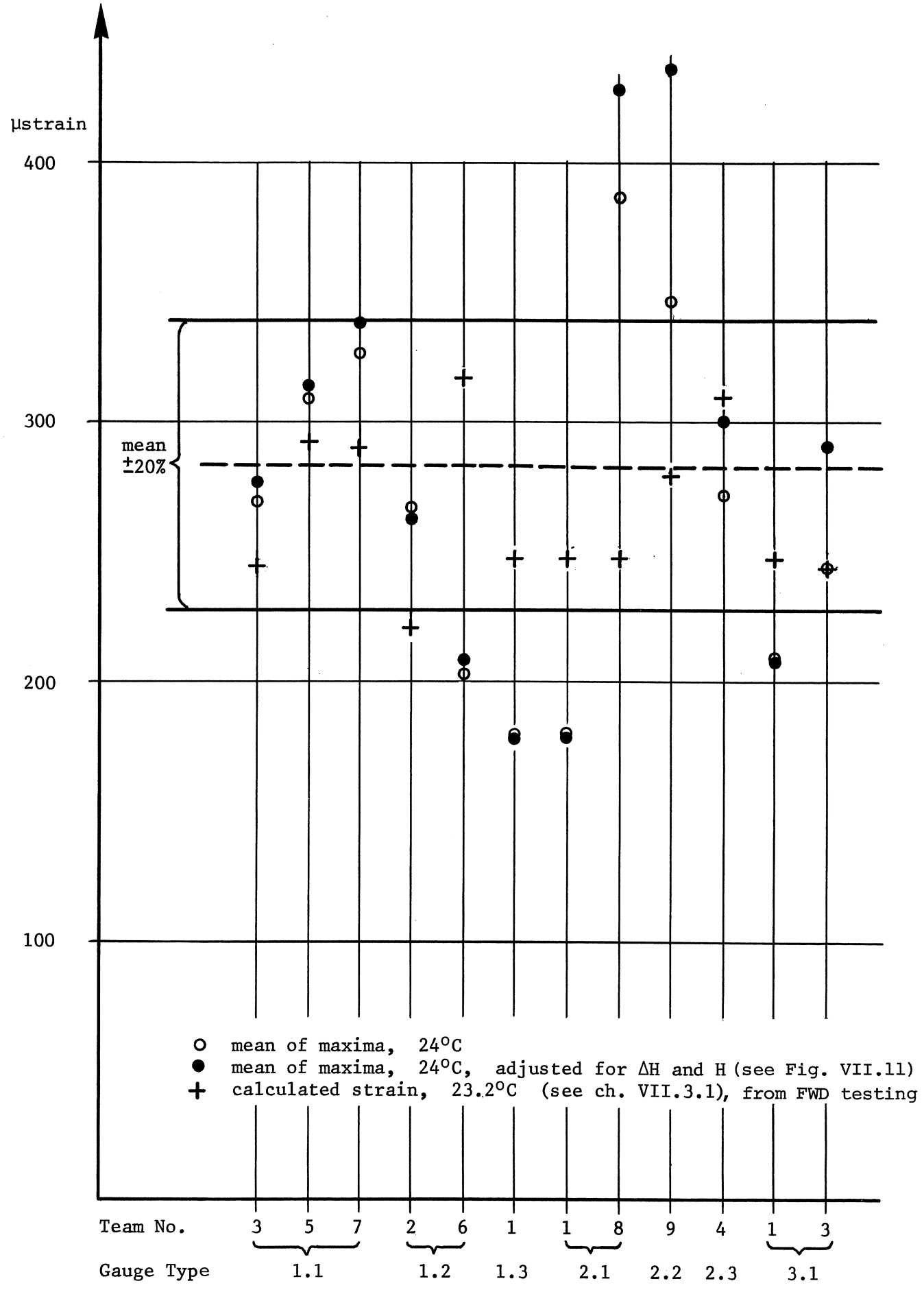

Figure VII.12 Strain values at 24°C

Chapter VIII

CONCLUSIONS

VIII.1 RESULTS OF THE FIELD EXPERIMENT

VIII.1.1 Data analysis and interpretation

The task of analyzing in a most comprehensive way the large amount of data provided by the experiment of Nardò is not necessarily an easy one, in particular when the usual working schemes of international expert groups are considered. The Group I2 took, therefore, the decision to create a Sub-Group dedicated to the analysis of the data and the preparation of this report, before the field measurements were carried out. The following work had obviously to be organized by way of distribution of partial studies and the preparation of summary reports on particular subjects. Chapters II to VII of the present report must thus be considered as the practical consequence of the mode of work chosen; in each of these chapters, prepared by different authors, only single aspects are treated, without the possibility of a complete analysis. Now that all the single pieces of the "puzzle" have been collected, a general "assembly" can be tried in the following.

It has already been mentioned, that many difficulties were encountered during the analysis of data and much emphasis has been given to the fact that various parameters, which before the tests had been estimated to be thoroughly controllable if not constant, actually appeared to be very variable:

- the condition of the pavement structure, discussed in detail in chapter IV, was characterized by a wider variation of many characteristic values such as layer thicknesses, material quality, bearing capacity (as shown by dynamic deflection),
- temperature conditions had obviously not been expected to remain constant during the three days of truck traffic; however nobody had foreseen the problems arising from the measurement of three different temperature values at the same nominal depth along a short stretch of 50 m of "homogeneous" pavement,
- the rear axle static load of one of the three trucks was 3.5 % higher and the large dispersion of the precision of passages also did not help to reduce the amount of scatter in the results.

Another very important point, which made the work of analysis and interpretation particulary difficult was the absence of knowledge about the "true" value of strain at each load passage. As indicated in detail in the previous chapters, different approaches were used and various additional studies were carried out in order to eliminate, as far as possible, some of the reasons for the variation of results and to find - or to try to find - what is likely to be the most probable "true" value from a logical point of view.

In this respect the analytical work described in Chapter VII.3.1 provides significant results. The determination of individual layer moduli for each team location based on the deflection bowls measured at a temperature of 23.2 °C with the FWD equipment eliminates variations deriving from different characteristics of the structure (bearing capacity, layer thickness and qualities). By the use of these moduli as input value in a layered pavement model for the calculation of strain values under a simulated dual wheel load also the effect of variation in the position of the load is eliminated. The comparison of these calculated values with those measured (mean of maxima) at similar temperature conditions (24 °C) shows an astonishingly good agreement for a number of teams and techniques. This agreement supports the assumption of a strain value of 270 µstrain as the average "true strain value" for those particular temperature and load conditions. (However, other calculations - Ch. VII.2.2 - show lower values. As no measurements were made on the unbound materials and the subgrade, both calculations are only rough estimates). From this form of analysis it follows that the results of the teams no. 1, 6, 8 and 9 are different from the others.

But as the true value has to be considered as unknown, any attempt to explain certain differences in the results of particular gauges will always remain a hypothesis. This could even be more than true in the case of these tests at Nardò, due to the very high degree of variation of different factors. Nevertheless, an attempt is made on the basis of available observations and logical considerations (see Ch. VII.5). From this last point of view it is also true that a high value in the result of the measurement is probably correct in itself (i.e. the measured amount of deformation corresponds to reality) while for lower values different reasons could be recognized.

a) Gauges showing higher values

As theoretical studies indicate, a frictionless condition between the granular base and the bituminous layer as well as different moduli and Poisson's values would easily lead to the higher values measured.

The strain gauges of teams 8 and 9 are glued directly to loaboratory specimens without any reinforcing third material (VII.4.1). The size of the specimens and the installation techniques are quite different. In spite of these differences the adjusted values are almost exactly the same (Fig. VII.11 and VII.12) as well as their strain-temperature relationship (Fig. VI.9 and VI.10). At lower temperatures, where the stiffness of the measuring systems has less effect (VII.4.1) the results of these teams agree quite well with those of other teams.

The presence of a higher pavement temperature - finally leading to increased strain - is, on the contrary, a more realistic hypothesis. Both gauges with higher values are mounted in fact on specimens (cubes, cylinders) prepared in the laboratory. Under the assumption of a good

compaction and high density of these specimens they would exhibit a different thermal conductivity than the surrounding material with poorer density as placed at Nardò. Such a phenomenon would not be expected in those cases when the surrounding material and the laboratory specimen are of the same quality.

b) Gauges showing lower values

While in the case of all other gauges calculated values tend to underestimate the measured value (exception: gauge type 2.3 of team no. 4 with very close values) calculations always over-estimate the measured value for the gauges showing lower results.

The gauges of type 1.2 used by team no. 6, similar in their general appearence to those of type 1.1, have a stiffer connecting bar (gauge support) between the two anchor ends. As indicated in the theoretical approach described in chapter VII.4, the increased stiffness of the gauge can cause a significant error (calculated value of the error $\sim$ 20 %).

No adequate explanation has been found for the results of the three types of gauges used by team no. 1. Considering the constant deviation of these results during all three days of measurement the assumption of a constantly lower temperature on the site of team no. 1 would not seem to be correct, although this possibility cannot be completely excluded (see Ch. V.5).

VIII.1.2 Success of the experiment

The results described and commented in the previous section are to be considered as very positive from the point of view of the initial question: are we all measuring the same values ? A large number of gauges used in different countries all lead - within acceptable limits of variation - to the same result under given test conditions. For the other gauges logical explanations have been found for the different results measured. Moreover, the good correlation found between measured values and the results of calculations using theoretical approaches also increases the level of confidence in the findings of the test.

The amount and variety of different additional studies carried out in order to help solving some, at times, very hard problems and their comprehensive presentation in this report provide a very unique and almost complete decription of possible techniques of strain measurements in bituminous layers and of many influencing parameters. In fact, all parts put together in this report represent a real state-of-the-art document. It would indeed be very hard to find other publications on the same subject as complete as this one.

The short time delays in the preparation and the organisation of the field experiement have caused some shortcomings in the form of a certain amount of improvisation and insufficient care given to the control of all parameters. However, the energy and determination demonstrated by the various participants in their own preparation work under pressure of time more than compensated for certain imperfections. What then still remained insufficient was outweighed by a very dedicated and active participation in the phase of the data analysis.

In terms of international cooperation, the field work phase provided an excellent example of collaboration of the various teams in a very open way. Thus the personal benefit in terms of practical experience was substantial for all. During the analysis of the data, detailed technical discussions on the results were as open as they could be, as they dealt with a subject involving equally all participants in the same experiment.

After the common test programme at Nardò problems associated with strain values measured in bituminous layers will no longer be of hindrance to international co-operation in the field of full-scale pavement testing. However, due to the variations of different parameters, the results obtained during the experiment at Nardò are not suitable for the verification of pavement design methodologies.

VIII.2 RECOMMENDATIONS

VIII.2.1 Recommendations for future international experiments

Should other common experiments of a similar kind be carried out, particular attention has to be given to the elimination of those factors which have caused major difficulties in the tests at Nardò. These difficulties can be summarized by just one word: variability. This variability affected mainly the following parameters.

- Pavement structure and quality. Everybody with at least some experience in pavement testing knows how difficult it is to obtain a so-called "homogeneous" pavement structure. Indeed, variability of the bearing capacity of a pavement over its length is very hard to be avoided. As this will almost never be done with success, additional efforts have to be taken for the verification of the actual condition of the foundation of the pavement with a very intense network of measuring points. Moreover, particular care has to be given during the placement of the component layers of the pavement both as to their regularity (a guarantee for homogeneous layer thickness) and as to their compliance to defined specifications. Such controls should also include supervision of materials at production plants.

- Loading. While certain variations in the magnitude of the load and the speed of the vehicles had little influence on the results, the transverse distribution of the loadings was of greater importance. With the use of vehicles, measurements of their transverse position should be done at much shorter intervals. Tests carried out on accelerated loading facilities like circular or linear test tracks would allow for a much greater precision and regularity in the load position and at the same time also permit a larger number of single measurements during the same period.

- Temperature. Absolute temperature control is only possible within an insulated environment with heating and cooling facilities. For experiments carried out in the open, where the influence of temperature is also one of the targets of the test, measures have to be taken in order to ensure

identical temperature conditions at the same time along the test pavement. Homogeneous material quality, already referred to as a must, helps in ensuring the same conditions of thermal conductivity. The same conditions of sunshine and wind exposure should also be provided along the whole test section. Additionally, temperature recording with the same type of equipment should be taken at various places along the pavement near to the placement sites of the other instruments.

VIII.2.2 Recommendations for strain measurements in bituminous layers

Considering the conclusions presented in chapter VIII.1 concerning the analysis of the results on the one hand and the experiences concerning mechanical stability of the gauges after placement and with time on the other - referred to in chapter III - the following recommendations can be made:

- strain gauges to be placed before or during construction of the pavement.

  Gauges of the type 1.1, as used by three different teams with minor modifications and a gauge carrier element of very low stiffness between the anchoring bars, thus corresponding to basic requirements from the physical point of view are recommended in the first place. These gauges have also shown a very limited number of losses after construction and also during the resistance control carried out 9 months after the gauges had been placed.

  Gauges of the type 2.3 also have given satisfactory results from different points of view and are economically very interesting. If they are cited here only in the second place, this is due to the fact that they rely only on one country's experience.

  Gauges of the type 1.2, as used by team number 2, give in principle satisfactory results. However, the rate of losses to be expected is a major disadvantage.

- Strain gauges for placement after construction of the pavement.

  Strain gauges which can be placed after construction of the pavement offer various advantages: they can be installed on pavements which previously had not been foreseen as a test section, they can be used to replace deficient instrumentation and they are not subjected to the risk of damage during construction operations.

  The type of gauge recommended by the group has not been tested directly at Nardò. Basically the ideal gauge for this purpose would be similar to type 3.1 as used by team no. 3 (fixed to material from the pavement). However, care should be given to avoid a large spacing between the core and the borehole in order to reduce the thickness of the glue, as has been done for the gauges of type 2.1 of team no. 8.

VIII.2.3 Recommendations for additional studies

The use of strain gauges corresponding to the recommendations indicated above should ensure an adequate comparability of the results obtained on different test sites, where these gauges will be used. In the case of the adoption of other types of strain gauges, in particular those which during the OECD common test program at Nardò did not give complete satisfaction, additional studies, on a national basis, should be carried out. In these experiments, the different hypothesis which have been made in this report for the explanation of the differences in the results should be verified. This applies in particular to the influence of differences in material characteristics between the constructed pavement and specimens prepared in the laboratory on the deformation behaviour and on thermal conductivity.

Also an effort should be made to find an explanation in those areas where the Group did not succeed.

Those agencies which will carry out test series within the scope - outlined above should make sure they circulate their findings among all interested organisations through the RTR secretariat of OECD and IRRD. This also applies to a comprehensive description of the results of additional measurements, i.e. in the upper layer of gauges and, exceptionally, also on the pavement surface. By proceeding in this way the additional studies will form a direct complement to this report and enlarge the possibilities of international co-operation in this field.

Annex A

INDIVIDUAL COMMENTS OF THE PARTICIPATING TEAMS

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INDIVIDUAL COMMENT OF TEAM NR. 1

Team Nr. 1 used three types of gauges with the goal of comparing the response of the different types. The means of the maxima measured for the three types of gauges were comparable, but considerably lower as compared to the results of the other teams (see Fig. VII.12).

These results can be explaned considering that temperatures measured by Team Nr. 1 were sistematically lower as compared to the ones measured by Team Nr. 3 and 9 (as reported in chapter V.5).

Considering that comparative tests carried out between the different systems showed that all the three systems were sufficiently accurate, the lower temperatures observed in the site of team Nr. 1 (due probably to the effect of different exposure to the wind) can justify the lower values of strains.

Team Nr. 1 considers the Nardò full scale common test a very important step for the development of knowledge in this research field and wishes to thank all the other teams for the wonderful spirit of cooperation.

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INDIVIDUAL COMMENT OF TEAM NR. 2

Previous experience

The H-Bar (type 1.2) gauges had previously been installed and tested by the research agency before the tests at Nardò.

The agency is monitoring the performance of highway test sections throughout the country and a total of 242 of the type 1.2 gauges were installed when these test sections were constructed between 1980 and 1982. 52.5% (127) gauges survived construction, though the number now operating in 1985 is far less.

Survival of the gauges at a particular site varies greatly depending upon:
a) the deflection of the surface on which the gauges are placed,
b) the bituminous mix design,
c) the tendency for the mix to flow during compaction,
d) the compactive effort used and
e) the thickness of the bituminous layer installed.

It is not possible to say how much each of these factors contributes to the survival or otherwise of a gauge except that:
i) it is most unlikely that gauges will survive vibratory compaction, regardless of lift thickness,
ii) when 18 gauges were placed in a test pavement, the deflection of the subgrade was 2.0 mm and no gauges survived construction, and
iii) when gauges were placed under bituminous layers only 30 mm thick, only 2 out of the 20 installed survived construction.

Comments on OECD results

The low survival rate of the type 1.2 gauges was disappointing and higher than that experienced in tests in our own country. Our main concern has always been that, whilst the type 1.1 gauge is more rugged and hence better able to survive construction, it may not record strains as accurately as the type 1.2 gauge because it is too stiff. The results suggest that the type 1.1 gauge did give satisfactory results and, because of this, we will seriously consider adopting the type 1.1 gauge in preference to the type 1.2 gauge in future experiments.

At this stage, we would not consider it justified to adopt the type 1.3 or type 2 gauges in our country.

Because of the many inherent variables in the Nardò tests, we will be proposing our own tests in our agency. We would propose to compare the performance of the type 1.1 and 1.2 gauges, with and without thin aluminium protective strips. We would also install thermocouples in the pavement to record temperature at various depths, and transverse location indicators - which we have developed - which record the location of a passing vehicle with respect to a reference line very accurately. These must be placed much closer to the gauges than was the case at Nardò. Other instrumentation which we would consider installing include deflection gauges - such as those used in conjunction with our full scale test facility.

We would also carry out deflection testing on the subgrade layers at construction because we believe that a factor affecting the survival rate of gauges may be the deflection of the layer on which they are placed.

The gauges we had used were 75 mm wide. This meant that the gauges and lead wires at Nardò were very close to each other. We are not sure whether this would lead to discontinuities in the pavement. Previous experience in our country when placing gauges under a thin pavement was that cracking was observed in the surface of the pavement along the location of the lead wired.

Data generated by the gauges already installed in our test sections throughout the country would also be analysed and compared with any new data.

We were very pleased to participate in the tests at Nardò and we wish to record our appreciation and thanks to all those who have assisted us. Any results which we obtain in future will, of course, be made available to the Group Members.

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INDIVIDUAL COMMENT OF TEAM NO. 3

Team Nr. 3 used two different types of gauges during the tests carried out in Nardò, gauges of the type 1.1 and gauges of the type 3.1.

We were surprised by the large amount of scatter in the temperature dependency of the gauges of type 1.1 on one side and also by the difference in temperature dependency of the two types of gauges used. From our point of view this second difference is depending to a large extent from the technique used in fixing the core into the pavement. In the next future we are going to carry out a series of tests on our own facility with another set of cores having almost the identical dimensions as the bore-hole, in order to reduce the thickness of the glue in the manner demonstrated by team Nr. 8 using gauges of type 2.1.

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INDIVIDUAL COMMENT OF TEAM NR. 4

The Full Scale Pavement Test Study provided a valuable exchange of technical information regarding instrumentation, testing techniques and data acquisition systems used to record pavement strains under moving wheel loads. Anticipated long term benefits derived from this international research project will be an increase in construction of field test facilities capable of monitoring pavement responses, and using these field measurements, the development of rational vehicle weight regulations and pavement design and evaluation processes.

Due to time and distance contraints, instrumentation installed by Team 4 at the Nardô site was limited to four strain carriers with embedded gauges. Two of these transducers, referred to as type 2.3 gauges in this report, were damaged during paving operations. At a pavement reference temperature equal to 24°C, the two remaining transducers yielded maximum tensile strains which were within two percent of the average of maximum tensile strains measured by all participating teams. In addition, recorded strains were in very close agreement with those calculated using analytical procedures. The relatively high loss of transducers during construction is not indicative of the success of numerous field installations carried out using these transducers. Prior to the Nardô experiment, approximately 50 type 2.3 gauges had been installed in a wide variety of pavement structures. Approximately 80 percent of these transducers survided loading imposed by construction traffic and many continue to be operational after 12 years of service. Pavement strains recorded under a wide spectrum of traffic loadings at these instrumented sites have been used to evaluate the relative potential damaging effect of traffic load variables on pavements. During the summer of 1984, 42 type 2.3 gauges were installed in a variety of inservice pavement structures. Thirty-nine, or 93 percent, of these installations were successful.

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INDIVIDUAL COMMENT OF TEAM NR. 5

The results of team Nr. 5 are close to the average value of all the measurements and to the estimated theoretical values.

The first assertion allows us to use the data from past experiments without any doubt on the validity of the strain values. In future we will use the same type of gauge and the same recording equipment.

In the short term we are considering:
- to reduce the number of identical measurements (same gauge, same number and magnitude of loadings, same temperature) since the variation is small,
- to maintain a high number of gauges since we still observe a large dispersion, that is to say that some gauges constantly give low values and others constantly give high values,
- to carry out a level control of the surface prior to the testing and to check the exact position of the gauges by taking cores after the test has been completed,
- to measure simultaneously the strain and the temperature for each gauge by inserting a Pt 100 sensor directly into the aluminium anchoring bar.

In the long term we consider:
- to study the use of instruments for the measurement of deflection under the rolling wheel, giving preference to contactless systems, and
- the implementation of a data acquisition system for the simultaneous recording of several parameters (strain, temperature, deflection).

In a more distant future we will consider the use of non-contact systems which would locate two non-deformable elements (as for example: two aggregates) and which would analyse continuously their relative position within the pavement.

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INDIVIDUAL COMMENT OF TEAM NR. 6

Team Nr. 6 used H-bar shaped gauges with an aluminium strip, in a similar manner to team Nr. 2. However, the cross section of this strip was larger in our case (0.8 mm^2) than for team Nr. 2 (0.3 mm^2).

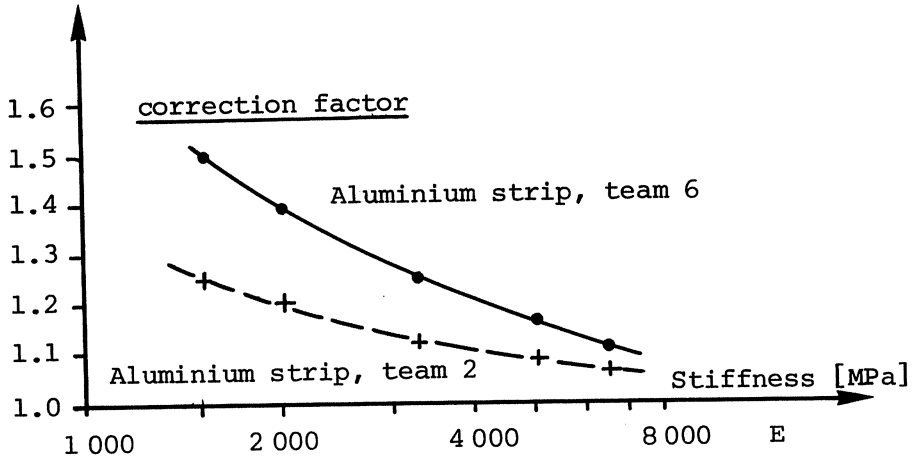
The gauges used by team Nr. 6 have shown the following when compared to the other systems used in Nardò:

1. A reduced sensitivity at a reference temperature of 24°C (203 compared to a mean value of 273 with a standard deviation of 67.8). It should be noted that the average value is quite close to the theoretical, calculated value (260).

2. The mean slope (a) as function of temperature in an equation of the type $\varepsilon = a\ \theta^{o} + b$, with a value of about 6.5 is also lower than the calculated mean value of roughly 14.

   This would suggest that the system used is too stiff in comparison to the stiffness of the surrounding material (which is the object of the analysis). During the tests the stiffness of the bituminous layers varied between 1600 and 6500 MPa.

   It is possible to find a correction function (using in particular the principles explained in section VII.4.1. of the report).



In spite of some important advantages of this type of gauge - solid construction contributing to high survival rates at the beginning and during controls 9 month later - we would suggest some modifications concerning:
- the width of the strip (reduction by a factor of 2), or
- the adoption of a plastic support for the foil. From this point of view the gauges used by the teams Nr. 3, 5 and 7 seem to be an acceptable solution even if their temperature dependency is not constant.

With reference to type 2 gauges, we feel that the difficulties of creating a priori the same material as the one of the pavement are not in favour of their use. Errors would in fact be possible in two directions (increased values for specimens with lower stiffness, reduced values for specimens with higher stiffness than the surrounding material). In view of the use of correction functions (which seem to be always necessary) it is an advantage to keep at least one parameter constant.

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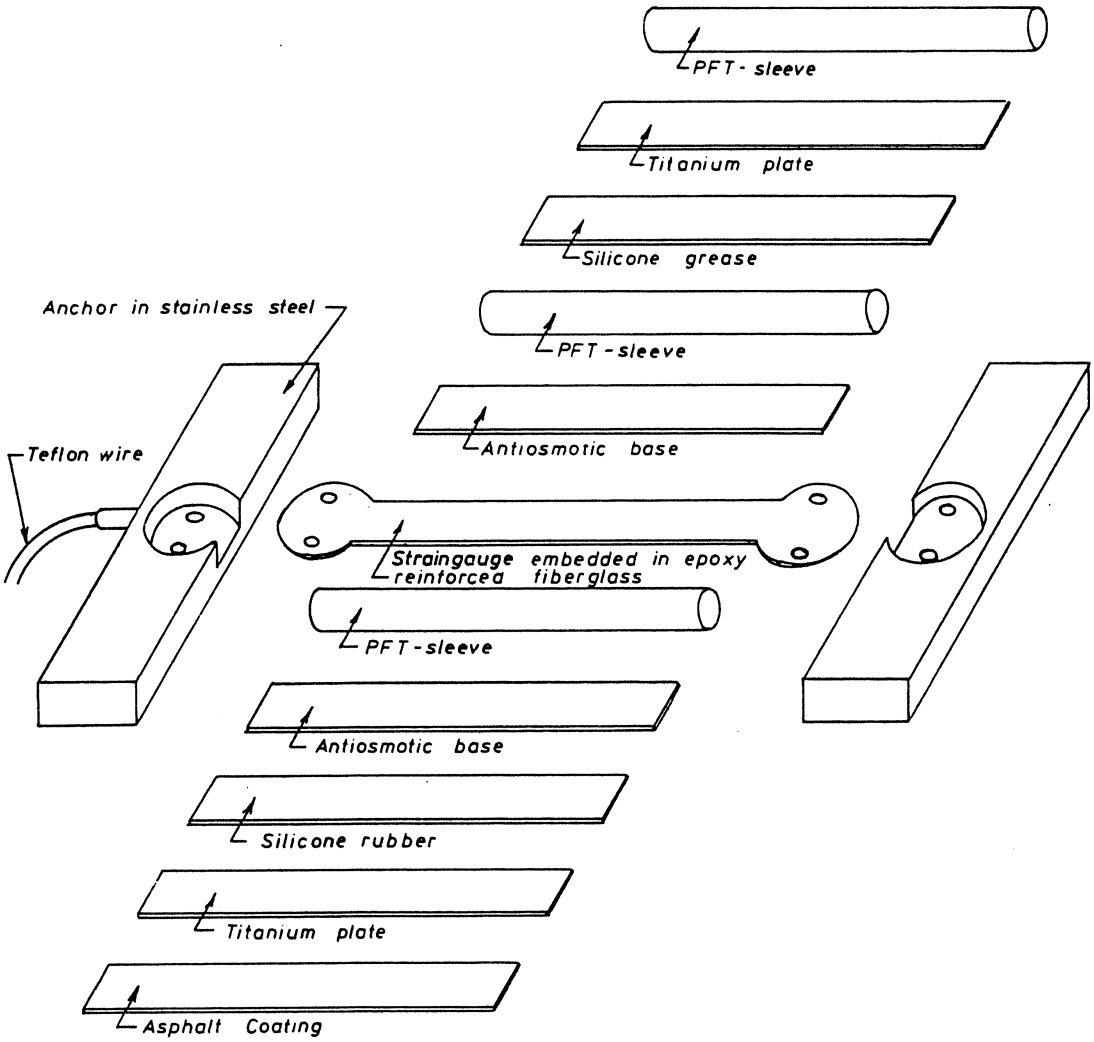
INDIVIDUAL COMMENT OF TEAM NR. 7

Since the experiment at Nardò a considerable development of the gauges used by team Nr. 7 has taken place. At the Nardò experiment the survival rate of the gauges was quite high due to the low asphalt temperature during compaction, the refrainment from vibratory compaction and the low number of loads during the testing. Normally 25% of the gauges are lost during installation and the rest of the gauges usually have a fatigue life of less than 10^4 cycles. At freezing temperatures the fatigue life is even shorter, because the gauges become brittle.

There are several reasons for this. One is that the gauge, according to the manufactures Kyowa is not intended for temperatures normally encountered during installation in asphalt pavements, the base material (acryl) crystalizes, causing a debond between the gauge and the base. In addition small air pockets in the base may expand, opening the gauge to moisture infiltration.

Normally the gauges used by team Nr. 7 are used for monitoring the response of pavements during performance tests with 10^5 - 10^6 loads and with varying climatic conditions. A new, and much more durable transducer has therefore been developed. The main components of this transducer are shown in the figure. When completed the transducer has a total of 27 layers.

These transducers have been tested under very severe conditions in the laboratory. Installed in asphalt they were submitted to dynamic strains from 300 - 1000 µstrains, with a mean value of 600 µstrains. After each 10^5 cycles the asphalt specimen was frozen to -20°C and during thawing the asphalt was soaked with water containing salt. More than 10^6 loads were applied to the transducers with no signs of distress occuring.


PFT - sleeve
Titanium plate
Silicone grease
Anchor in stainless steel
PFT - sleeve
Antiosmotic base
Teflon wire
Straingauge embedded in epoxy reinforced fiberglass
PFT - sleeve
Antiosmotic base
Silicone rubber
Titanium plate
Asphalt Coating

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INDIVIDUAL COMMENT OF TEAM NR. 8

The gauges can be divided into two categories, those without any third material (teams 8 and 9) and those with a third material (H-bar, metal or plastic or cores with thick glue layer). The installation techniques of the former ones differ from each other, however, the corrected values and the temperature dependency is the same. At lower temperatures the measured strains are the same as, for instance, those of team 7. This leads quite naturally to the conclusion that a third material strengthens the gauge and makes it stiffer and thus those gauges give lower values if the stiffness modulus of the asphalt pavement is low (high temperature or slow traffic). In the Nardô-case temperatures were up to 32°C, the speed was abnormally slow (30 km/h) and the bitumen was very temperature susceptible, which increases the influence of high temperatures.

Our normal procedure is to drill a core specimen from the pavement to be used in strain gauge measurements or to make a core specimen similar to the pavement in laboratory. In the Nardô-test the former was not possible and for the latter the necessary information was lacking. Our core specimens were denser than the Nardô asphalt surfacing which was poorly compacted at low temperature. The influence of different density on the results is difficult to estimate.

The results were compared to the theoretical calculations made by multilayer computer programs. No direct measurements of modulus of elasticity were made on subgrade, subbase or base course but the values are based on indirect measurements made at relatively low temperatures by a falling weight deflectometer. The stiffness moduli of asphalt layers were determined in laboratories. The measured values of ours and those of team 9 were larger than calculated in higher temperatures, where asphalt pavements behave more viscoelastically and less elastically. Though the calculation method has been generally approved and everywhere widely used for pavement design there is no exact proof especially in the viscoelastic region (higher temperatures and/or low speed). In any case viscoelastic models tend to give higher values than elastic with corresponding stiffness modulus.

There is serious doubt, too, that dynamic loads at low frequencies cause greater strains than static loads and that the corresponding frequency used in determining a suitable stiffness modulus from laboratory tests is too high. More detailed analysis is necessary and will be done in order to evaluate the theoretical calculations.

The compacting effort was kept low at Nardô (no vibratory compaction, low compacting temperature) in order to spare strain gauges. The survival rate after installation was higher than generally. The resistance of the gauges was measured in January 1985. According to those measurements only one of our twelve gauges was working. We had cut our cables very short and according to the measurement protocol only ten of our twelve cables even found. We are afraid that because of this kind of difficulties other measurements were not carried out carefully. We installed

twelve gauges in our own test field last autumn in poor weather conditions. Seven were working in March and our winter is much harder than the Italian winter. We have no real experience in long time or fatigue properties of our gauges by now, but because our gauges are installed after laying the asphalt pavement, new gauges can be added if some fail. The failure of a gauge can be seen very easily because the signal drops to a lower level. The position of a strain gauge is known exactly and there are no problems due to the movements of a gauge during construction.

The Nardò test has proved to be very useful for us and we are encouraged to use the same method though the manufacturing and installing of the gauge specimens call for meticulous care (the tolerance is 0,5 mm or less). It is very likely that we will also use the system of team number 9 during the summer 1985 but will have longer strain gauges and larger asphalt specimens, and also H-bar strain gauges for comparisons.

We were very pleased to participate in the Nardò-test. The arrangements and the cooperation between teams were excellent. The handling of data was demanding and gave new ideas and aspects. We hope that the success of the Nardò-test will stimulate new international cooperation.

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INDIVIDUAL COMMENT OF TEAM NR. 9

First of all, Team Nr. 9 wishes to express its feelings of pride and happiness with the hearty and frank atmosphere in which the international coordinated measuring campaign took place at Nardò.
There was much to learn, among other things the following:

- how to undertake strain measurements after a pavement is finished
- the absolute necessity of measuring strain and temperature at the same point and time
- the necessity of applying several methods of evaluating layer moduli in a nondestructive manner, measuring on the surface of the pavement
- and, last but not least, the absolute necessity of international cooperation for successful research work.

Nevertheless, some additional remarks have to be made. The success of the strain measurements in Nardò is essentially based on the comparison between measured and calculated strains. The calculated strain values are derived from measurements of the deflection basin under the impact load of a "Falling Weight Deflectometer" (FWD). The moduli of the layers of a linear elastic multi-layered model are then varied till the calculated and real deflection basin are nearly equal. The model, having the moduli obtained in the above-mentioned manner, is then used to calculate the strains at the lower level (subsurface) of the bituminous layer, produced by the rear wheel load of a test truck moving at a speed of 30 km/h. In doing so, the El-modulus of the asphalt layer, valid for the 25 ms load duration of the FWD, has to be converted to the modulus valid for the 115 ms truck load. This was achieved by reducing the FWD modulus by 25 percent. To verify this procedure, Team Nr. 9 conducted laboratory tests on Nardò samples under a compressive force. Samples were loaded by means of a continuous sinusoidal force on the one hand and sinus-shaped single load pulses on the other hand.

The results showed that a modulus E_{eff} (valid for single pulses) derived from an FWD load pulse (25 ms) equals a continuous sinusoidal load modulus $|E|$ at a frequency of 8 Hz while a 115 ms strain pulse, which is comparable to that under a truck rear wheel load, leads to a modulus E_{eff} which is equal to a modulus $|E|$, measured at a frequency of 3 Hz. This leads to a reduction of El by about 0.67 when applying the calculated FWD El-values to the calculation of the strains produced by the truck. This can be done both for friction and frictionless conditions between the upper two layers of the above model.

As to the strain values measured by Team Nr. 9, it should be pointed out that, at a temperature of 16°C, they correspond closer to the calculated ones than shown on Fig. VII.11 which is representative for a temperature of 24°C. The higher the temperature is, the poorer the correlation of the values will be. This is indicative of a temperature effect. But the reasons for this effect have not been found yet. The correspondence is still closer if the means of the strain values of Team Nr. 9 are taken

and not the means of the maxima as was done during the evaluation procedure. Due to the short length of the gauges of Team Nr. 9 (20 mm) and the reduced dimensions of the 2.2-type gauges, strains within the asphatic layer are measured at nearly converging points without any spatial integration effect. Such an effect exists for H-shaped gauges and long strain gauges glued to 100 mm diameter cores. However, the Team-9-method includes the drawback of a large standard deviation of strain values, being much larger than that of other methods.

The advantage of a strain gauge of shorter length is the lower loss rate. However, due to the relatively low asphalt temperatures and the lack of vibration during the compaction work, this did not play a role in Nardò anyway. The consideration above is supported by the fact that only slight variations of strain values were observed during the passages of the three trucks but remarkably larger variations indicated by the different gauges. These can be related to pavement inhomogeneities.

OECD RTR I2 FULL SCALE PAVEMENT TESTS
Report: Strain measurements in bituminous layers , Annex A

INDIVIDUAL COMMENT BY MR. J. VERSTRAETEN, BELGIUM
(Member of the Group, did not participate in the field experiment)

In spite of the dispersion shown by the results of elongation measurements, due to a considerable extent to the variability of the materials used and the uneven temperature variations in the bituminous courses, it is rather remarkable to find that the results of the experiment on an average confirm the results forecasted by models based on elastic multilayers theory. From this point of view, the Nardô experiment has made a contribution to the solution of the important problem of the experimental verification of the validity of theoretical models.

Another significant contribution concerns the experimental determination of the moduli of bituminous materias. Indeed it has been found that there is an excellent agreement between the results obtained by laboratories using different test methods. This should be seen as a sign that the "modulus" concept does have physical significance and may be considered as trustworthy on this basis.

Emphasis should also be laid on the excellent spirit of co-operation among the teams of the participating countries and the great enthusiasm shown by them. Such working conditions are bound to have an effect on future progress in elongation measurements, which are so necessary for the experimental verification of theoretical models.

It is to be hoped that such experiments in co-operation will be conducted again in the future. When integrated into national programmes, they could lighten the budgets and yield sufficiently general results leading to a more efficient use of research results for solving problems encountered in practice.

OECD RTR I2 FULL SCALE PAVEMENT TESTS
Report: Strain measurements in bituminous layers, Annex A

INDIVIDUAL COMMENT BY MR. W. KENIS, FHWA, USA
(The funding agency FHWA did not participate in the field experiment)

The report concludes that "... a large number of gauges lead to the same result ... and ... the good correlation found between measured values and the results of calculations using theoretical approaches also increases the level of confidence in the findings of the test".

Although this statement is true, the crucial point in pavement design is the abilitiy to predict reliable estimates of pavement damage, viz. cracking and ruttings. Thus, two questions must be answered:

1. Are mean calculated strains (or deflections) over the analysis period within an order of magnitude sufficient as input for the reasonable calculation of pavement damage (cracking or rutting)?

2. Is a specific calculated strain, at a given point in time over the analysis period, within a reasonable tolerance such that estimates of cracking and rutting are also within reasonable tolerances?

Note that in neither question has it been stated that measured strains must be equal to calculated, however, it is inherent that knowledge of the real or measured strain levels are necessary for improving the layer theory models and thus in developing accurate damage models. The first question then implies a reasonable "tradeoff" between measured and calculated strain and the prediction of damage. Thus, if excellent predictions of pavement damage (cracking and rutting) are achieved using calculated strain (deflection) and if the calculated strain values are not precisely those which are measured, would this still be a sufficient condition for pavement design? The results of the I2 study do, in fact, relate that the magnitudes of measured strain are in reason with those estimated by layer theory and this should, in itself, establish that layer theory is sufficient for use in pavement design, viz. for use with other damage functions for cracking and rutting. The study did not show that the strain levels computed were sufficient for accurate prediction of cracking and rutting, however, others have demonstrated that they are.

The second question, however has not been answered specifically. To demonstrate this point, the following figure is a plot of strain on the bottom of a 200 mm thick-asphalt layer with a 400 mm base and subgrade having moduli of 280 MPa and 35 MPa respectively. The computed strain, using layer theory, is plotted against five AC layer moduli ranging between 140 MPa and 14 000 MPa (typical range of AC over the seasons of the year). From the information provided by the I2 study, one can assume that calculated strain (e_c) could be 33 percent less than measured strain (e_m). These points are shown on the figure. The increases in modulus are of somewhat greater order, 81 percent and 136 percent. Refer now to the fatigue equation

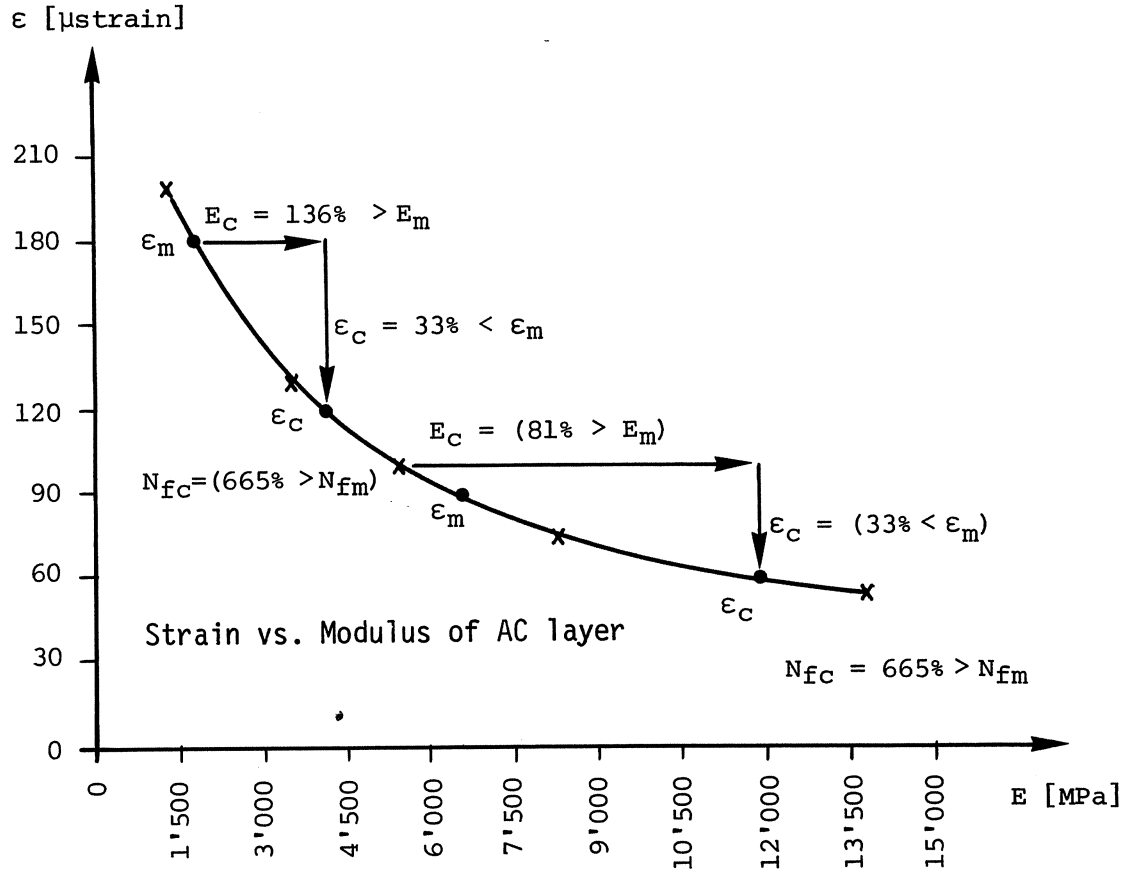
$$N_f = K_1 \ (1/e)^{K2}$$

and calculate the percent change in fatigue life for a value of

$$K_2 = 5.00.$$

We find that the calculated fatigue lives are 665 percent greater than the fatigue lives which would have been calculated using measured strain. Thus a 33 percent reduction in strain results in an increase in modulus (depending upon strain level) and a very large increase in fatigue life.

This analysis is only intended to demonstrate the significance of variation in strain on damage prediction and that future efforts should develop research keeping this point in mind.



Annex B

RAW DATA FROM THE FIELD TEST PROGRAMME

Annex B.1. Truck speed 130
Annex B.2./B.3. Temperatures 131
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measurement results 133

Truck speed (km/h), vitesse des camions (km/h)

No. passage	Truck / Camion		
	A	B	C
9. 4. 1984			
0	33.4	33.4	36.0
1	30.5	31.5	29.4
2	30.7	34.7	30.2
3	30.5	30.1	32.2
4	29.7	32.8	31.7
5	31.2	32.8	30.7
6	31.2	33.4	31.7
7	30.2	31.2	29.5
8	36.0	31.2	30.7
9	31.6	32.9	29.3
10	31.2	30.7	29.3
11	31.7	31.2	29.3
12	31.2	30.2	30.2
13	32.8	31.7	30.6
14	30.2	32.3	32.3
15	31.7	32.3	31.2
16	32.2	31.2	31.7
17	33.4	30.7	33.5
18	32.3	30.2	31.2
19	32.3	32.5	30.2
20	34.7	32.3	31.2
21	31.2	30.6	29.3
22	32.8	32.3	32.8
23	-	-	-
24	-	-	-
10. 4. 1984			
25	27.5	26.0	31.2
26	30.2	31.2	33.4
27	29.2	31.2	32.2
28	27.7	30.6	31.5
29	30.7	31.2	31.2
30	28.9	30.2	31.7
31	28.9	30.6	29.1
32	29.6	29.7	31.7
33	31.3	33.4	32.3
34	34.7	31.7	33.4
35	30.2	30.7	31.2
36	29.2	33.4	33.4
37	30.7	X	29.2
38	33.4	X	29.3
39	X	X	29.3
40	31.7	X	31.2
41	31.2	X	29.3
42	33.4	32.3	31.2
43	33.4	31.7	30.2
44	31.7	31.7	31.2
45	31.2	31.7	32.2

No. passage	Truck / Camion		
	A	B	C
46	30.2	32.3	31.2
47	29.7	29.7	31.2
48	31.2	33.4	29.3
49	-	-	-
50	30.7	31.2	29.3
51	-	-	-
52	33.4	31.7	28.4
53	30.7	33.4	27.5
54	32.3	30.7	31.2
55	31.2	31.7	28.4
56	30.7	31.7	28.8
57	31.2	31.7	31.2
58	29.3	31.2	30.7
59	31.2	31.2	33.4
11. 4. 1984			
60	31.2	34.7	31.2
61	32.2	33.4	31.2
62	30.2	34.7	29.3
63	31.2	31.2	32.3
64	31.2	33.4	30.2
65	33.4	33.4	32.3
66	-	-	-
67	30.2	33.4	30.2
68	-	33.4	31.2
69	-	33.4	30.2
70	-	32.3	30.0
71	-	33.4	29.3
72	-	33.4	26.0
73	31.2	34.6	32.3
74	32.3	36.0	27.5
75	31.2	39.0	32.3
76	33.4	34.5	24.6
77	-	31.2	29.3
78	32.2	33.4	31.2
79	33.4	33.4	25.3
80	-	32.3	30.7
81	32.8	33.4	29.3
82	33.4	33.4	30.2
83	33.4	33.4	33.4
84	33.4	32.3	32.3
85	33.4	32.3	29.3
86	34.7	32.3	30.2
87	31.2	33.4	30.2
88	34.7	32.3	31.2
89	36.0	34.7	26.7
90	-	-	-
91	-	-	-

Temperatures

Annex B.2

Nº de/of passage	Heure Time	AIR [°C]			- 50 mm [°C]			- 130 mm [°C]			Analysis value
		team 1	team 9	team 3	team 1	team 9	team 3	team 1	team 9	team 3	
	9. 4. 1984										
1	11.17		21.9	20.2	21.0	23.1	28.4	16.5	18.4	20.6	23.2
2	11.28		21.1	20.2	21.0	23.7	29.4	16.5	18.7	21.3	24.0
3	11.34		21.5	20.1	21.3	24.2	29.6	16.8	19.0	2.15	24.2
4	11.47		21.5	20.1	21.6	24.7	30.0	17.0	19.3	21.8	24.5
5	11.57		21.7	21.8	21.7	25.2	30.3	17.2	19.7	22.0	24.8
6	12.06		21.7	22.1	22.2	25.7	31.0	17.4	19.9	22.4	25.3
7	14.28		21.2	21.6	25.1	30.1	35.6	19.9	24.0	27.2	30.0
8	14.39		20.6	21.2	25.2	30.2	35.6	20.1	24.2	27.4	30.1
9	14.48		20.7	21.0	25.2	30.3	35.8	20.2	24.4	27.6	30.3
10	14.58		20.3	21.2	25.3	30.4	36.0	20.3	24.6	27.8	30.5
11	15.08		20.5	20.9	25.5	30.6	36.2	20.4	24.8	28.2	30.9
12	15.50		19.8	21.3	25.6	30.6	35.8	20.8	25.4	28.9	31.2
13	15.59		19.7	21.1	25.8	30.5	35.8	21.0	25.6	29.1	31.3
14	16.08		19.4	20.8	25.7	30.4	35.4	21.0	25.7	29.2	31.3
15	16.17		19.4	20.4	25.6	30.2	35.2	21.1	25.7	29.4	31.3
16	16.27	19.9	19.2	19.6	25.6	30.0	34.8	21.1	25.8	29.2	31.1
17	16.35	19.7	18.5	19.3	25.5	29.8	34.4	21.2	25.9	29.3	31.0
18	16.45	19.4	18.0	19.2	25.3	29.4	34.0	21.2	25.9	29.4	30.9
19	17.14	18.6	17.3	18.3	24.7	28.3	32.1	21.2	25.9	29.6	30.4
20	17.23	18.3	17.1	17.9	24.6	27.9	31.7	21.2	25.8	29.4	30.2
21	17.32	18.2	16.8	17.6	24.3	27.6	31.2	21.1	25.8	29.2	29.9
22	17.41	17.9	16.7	17.2	24.0	27.2	30.7	21.1	25.7	29.1	29.6
23	17.50	17.7	16.4	17.0	23.8	26.8	30.2	21.0	25.6	29.2	29.5
24	17.59	17.5	16.2	16.7	23.6	26.5	29.8	20.9	25.5	29.2	29.4
	10. 4. 1984										
25	9.51	18.0	18.4	19.0	16.2	18.0	22.0	14.1	15.9	17.8	19.2
26	10.01	18.2	19.1	19.5	16.8	18.6	22.7	14.2	16.1	18.1	19.6
27	10.10	18.5	19.3	19.7	17.2	19.2	23.7	14.3	16.4	18.3	20.1
28	10.21	18.8	19.3	19.9	17.6	19.9	24.2	14.5	16.6	18.5	20.4
29	10.30	18.7	19.2	20.2	18.0	20.5	25.4	14.7	16.9	18.9	21.1
30	10.40	19.5	20.0	20.6	18.3	21.1	26.0	14.9	17.2	19.2	21.5
31	10.50	19.6	20.1	20.5	18.4	21.7	26.9	15.1	17.5	19.4	21.9
32	11.28	19.4	20.3	21.3	20.1	24.2	30.0	16.8	18.6	21.1	24.1
33	11.36	18.6	20.7	19.0	20.5	24.6	30.8	16.0	18.9	21.6	24.7
34	11.46	19.3	19.8	18.2	20.9	24.8	31.1	16.2	19.3	22.1	25.1
35	13.32	18.3	18.2	18.0	23.2	26.7	31.3	18.3	22.2	25.3	27.3
36	13.42	18.2	17.4	18.0	23.1	26.3	30.8	18.5	22.4	25.6	27.3
37	14.31	18.3	17.9	18.1	22.6	25.0	29.0	18.9	22.5	25.7	26.8
38	14.40	18.2	17.3	18.0	22.6	24.9	28.8	18.9	22.5	25.7	26.7
39	14.50	18.7	18.0	18.2	22.5	24.8	28.5	18.9	22.5	25.8	26.7
40	14.58	18.6	17.5	18.0	22.5	24.8	28.6	19.0	22.5	26.0	26.9
41	15.07	18.0	17.6	17.9	22.4	24.7	28.7	19.0	22.5	25.9	26.8
42	15.48	18.0	18.1	18.1	22.5	25.0	28.9	19.1	22.6	26.0	27.0
43	15.58	18.3	17.7	18.1	22.5	24.9	28.7	19.1	22.6	26.1	27.0
44	16.07	18.6	17.7	18.1	22.5	24.7	28.4	19.1	22.7	26.0	26.8
45	16.16	19.0	18.1	18.6	22.5	24.8	28.5	19.1	22.7	26.1	26.9

Nº de/of passage	Heure Time	AIR [°C]			- 50 mm [°C]			- 130 mm [°C]			Analysis value
		team 1	team 9	team 3	team 1	team 9	team 3	team 1	team 9	team 3	
46	16.26	18.9	18.3	18.7	22.5	24.8	28.7	19.2	22.7	26.2	27.0
47	16.36	19.0	18.0	18.6	22.5	24.9	28.8	19.2	22.7	26.1	27.0
48	16.59	18.1	17.9	18.0	22.6	25.0	28.6	19.3	22.7	26.1	26.9
49	17.08	17.9	17.2	17.3	22.6	24.9	28.8	19.3	22.9	26.2	27.1
50	17.17	17.9	17.2	17.3	22.6	24.8	28.4	19.3	22.9	26.2	26.9
51	17.26	18.0	17.1	17.3	22.6	24.6	28.1	19.3	22.9	26.2	26.8
52	17.35	17.8	17.0	17.3	22.5	24.4	27.8	19.3	22.9	26.2	26.7
53	17.44	17.1	16.7	16.8	22.5	24.2	27.7	19.4	22.9	26.3	26.8
54	17.52	17.2	16.6	16.3	22.4	23.9	27.4	19.3	22.9	26.3	26.7
55	18.03	17.1	16.7	16.2	22.3	23.7	26.9	19.4	22.8	26.2	26.4
56	18.12	16.8	16.5	15.8	22.2	23.5	26.7	19.4	22.8	26.3	26.4
57	18.20	16.2	15.7	15.3	22.0	22.9	26.1	19.4	22.7	26.2	26.2
58	18.38	15.1	14.7	14.4	21.7	22.6	25.1	19.3	22.6	26.0	25.7
59	18.48	14.5	14.1	13.8	21.7	22.2	24.4	19.3	22.6	25.5	25.1
	11. 4. 1984										
60	9.30	16.7	15.3	15.9	17.0	15.9	17.9	15.3	16.2	17.7	17.8
61	9.41	17.4	16.7	16.6	17.1	16.4	18.8	15.3	16.3	17.8	18.1
62	9.50	17.4	16.8	16.8	17.3	16.9	19.5	15.4	16.4	17.9	18.4
63	10.00	17.4	16.4	16.7	17.5	17.4	20.0	15.4	16.5	18.1	18.7
64	10.09	17.1	16.0	16.2	17.7	17.9	20.2	15.5	16.6	18.2	18.9
65	10.19	16.6	15.5	15.9	17.9	18.3	20.5	15.6	16.8	18.4	19.1
66	10.28	16.6	15.4	15.9	18.1	18.4	20.4	15.7	16.9	18.7	19.3
67	10.38	16.7	15.4	16.2	18.3	18.6	21.0	15.7	17.1	19.9	20.3
68	11.17	17.6	16.6	16.7	18.8	18.7	22.2	16.1	17.2	19.6	20.5
69	11.27	17.6	16.7	16.7	18.9	19.6	22.3	16.2	17.7	19.7	20.6
70	11.35	17.5	16.5	16.6	19.0	19.9	22.7	16.2	17.8	19.9	20.8
71	11.44	17.2	16.1	16.5	19.2	20.2	23.2	16.3	17.9	19.9	21.0
72	11.54	17.1	15.9	16.4	19.3	20.4	23.2	16.4	18.1	20.0	21.1
73	12.03	16.9	15.8	16.4	19.4	20.5	23.0	16.5	18.2	20.1	21.1
74	14.26	18.7	17.2	18.1	20.5	23.2	26.1	17.4	19.7	21.6	23.1
75	14.36	18.9	17.4	17.6	20.8	23.3	26.6	17.4	19.8	21.8	23.4
76	14.45	17.7	16.4	16.9	21.1	23.5	26.8	17.6	19.9	21.9	23.5
77	14.54	17.4	16.4	16.8	21.3	23.5	26.6	17.6	20.1	22.2	23.7
78	15.03	16.7	15.6	16.7	21.4	23.4	26.4	17.7	20.3	22.4	23.7
79	15.12	17.5	16.0	16.5	21.4	23.2	26.4	17.8	20.4	22.6	23.9
80	15.45	18.0	16.2	16.9	21.4	23.0	26.0	18.1	20.7	22.7	23.8
81	15.52	18.3	16.6	17.1	21.4	23.1	26.1	18.2	20.8	22.9	24.0
82	16.02	18.3	16.7	17.4	21.5	23.4	26.0	18.3	20.8	23.0	24.0
83	16.10	17.8	16.4	16.8	21.6	23.6	26.5	18.3	20.9	23.2	24.3
84	16.19	17.2	16.1	16.8	21.6	23.6	26.5	18.4	20.9	23.3	24.4
85	16.23	17.5	16.0	16.8	21.6	23.5	26.1	18.4	21.0	23.5	24.4
86	16.56	17.6	16.0	16.4	21.8	23.4	25.3	18.6	21.2	23.4	24.0
87	17.03	16.7	15.3	16.0	21.8	23.3	24.9	18.7	21.3	23.3	23.8
88	17.14	16.4	15.0	15.4	21.8	23.0	24.7	18.7	21.3	23.3	23.8
89	17.23	16.3	14.7	15.2	21.7	22.6	24.5	18.8	21.3	23.5	23.8
90	17.32		14.6	15.0		22.3	24.5		21.4	23.5	23.8

Team no. 1: STRAIN MEASUREMENTS RESULTS Annex B.4

GAUGE GROUP 101-111-121-131

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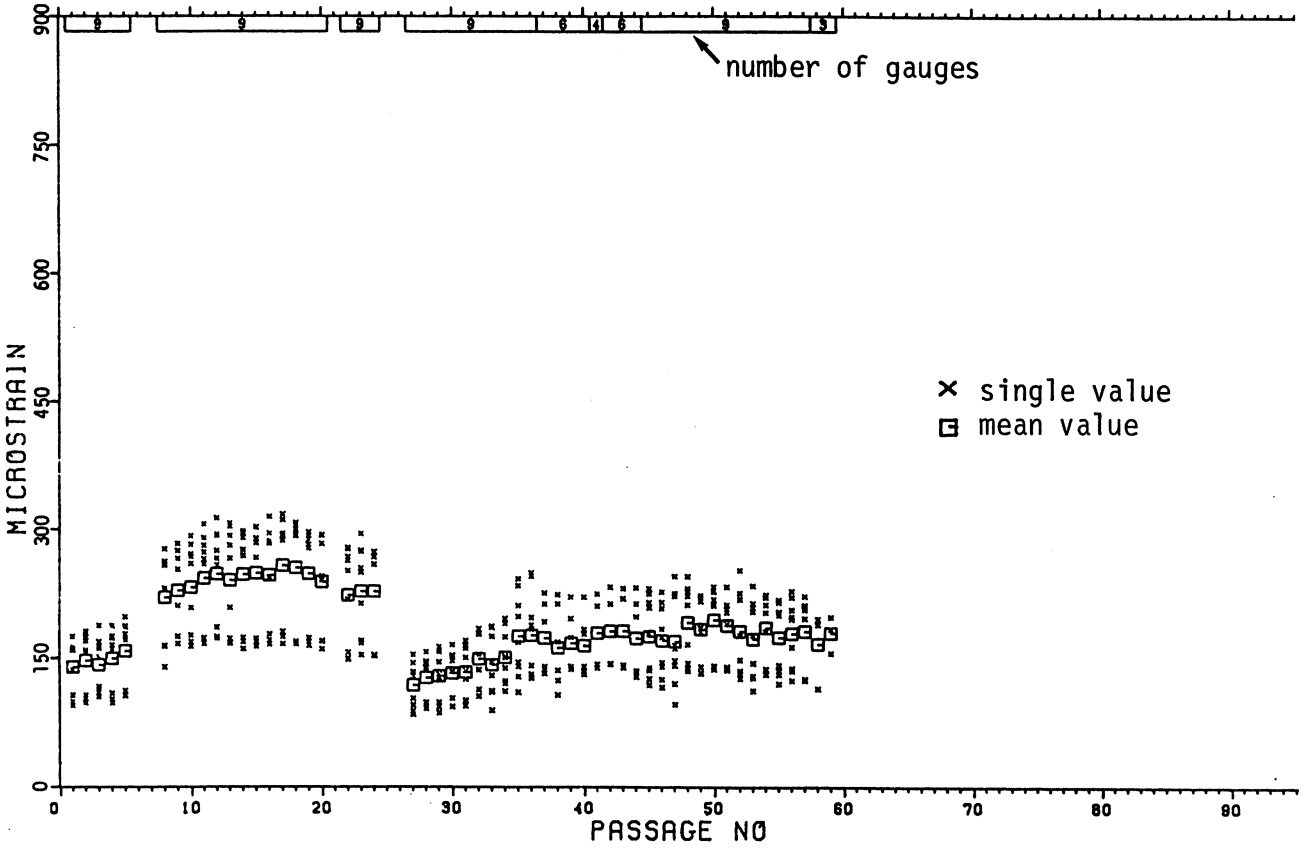

GAUGE GROUP 102-112-122-132

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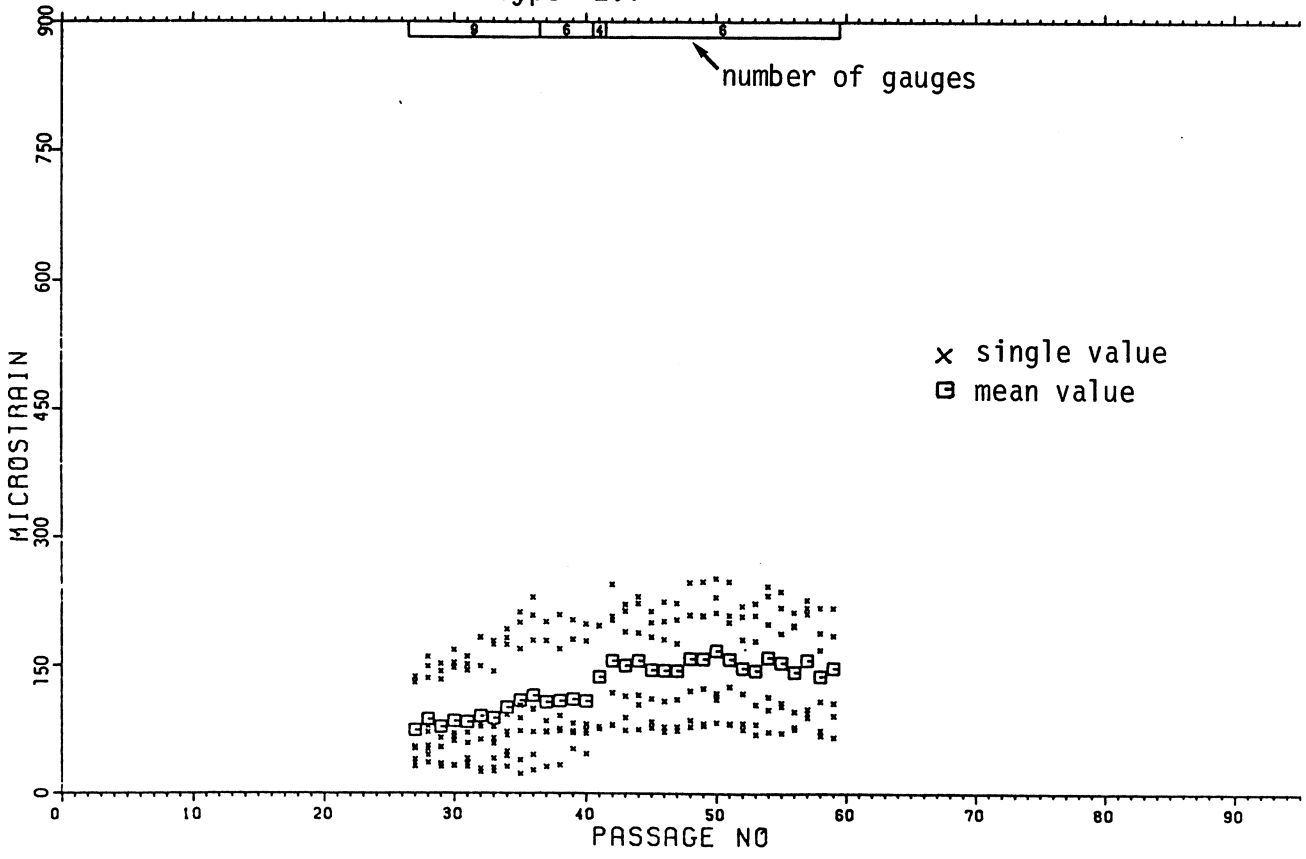

Team no. 1: STRAIN MEASUREMENTS RESULTS Annex B.5

GAUGE GROUP 103-113-123-133

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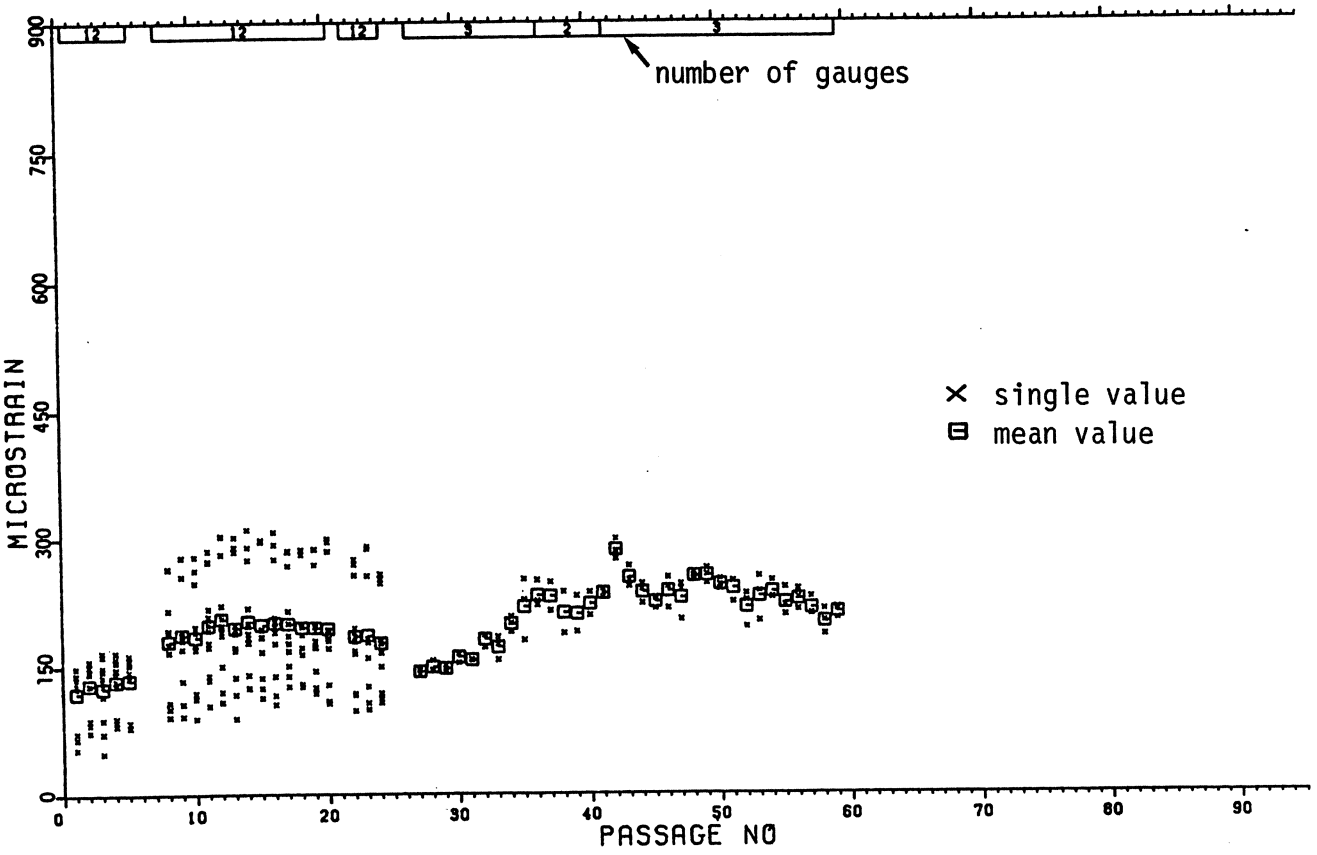
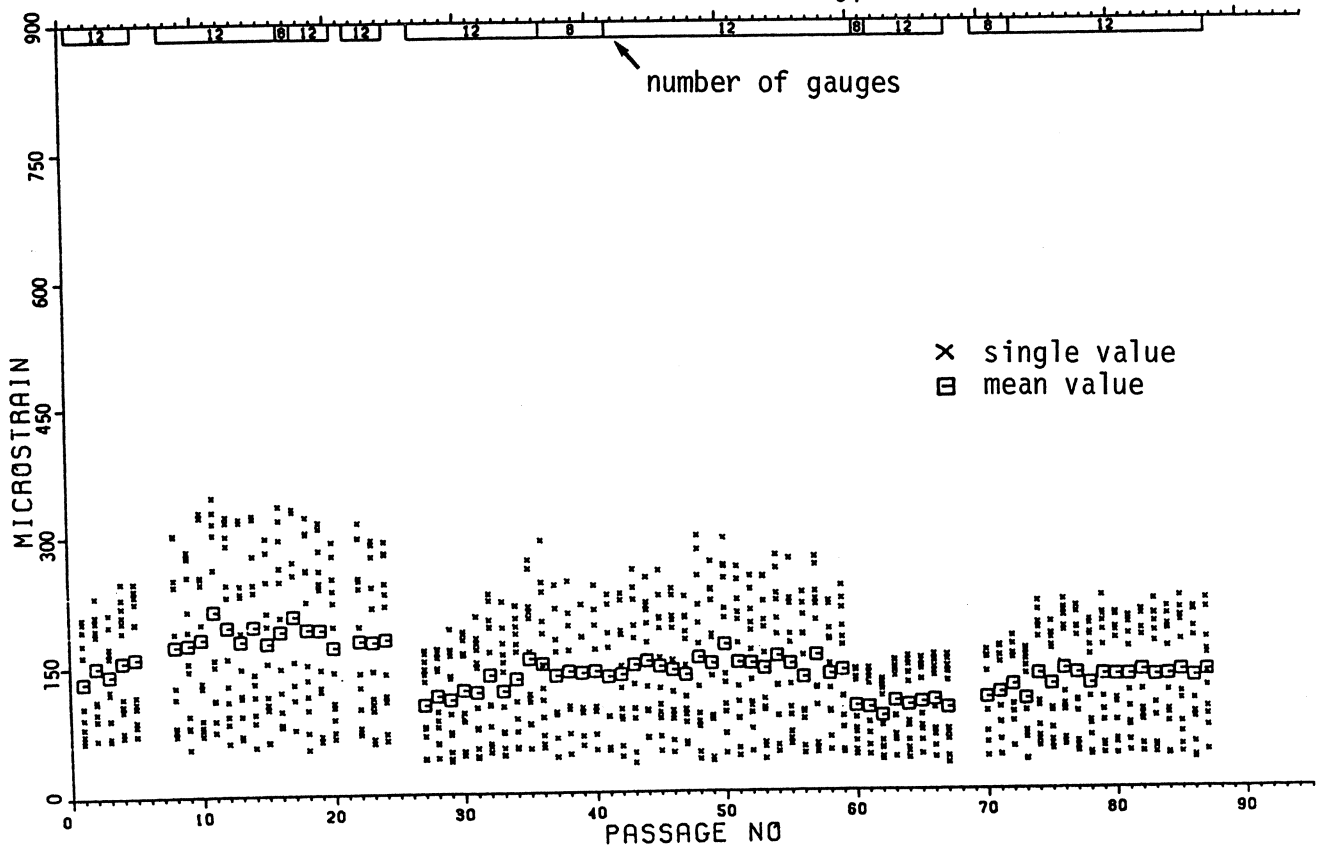


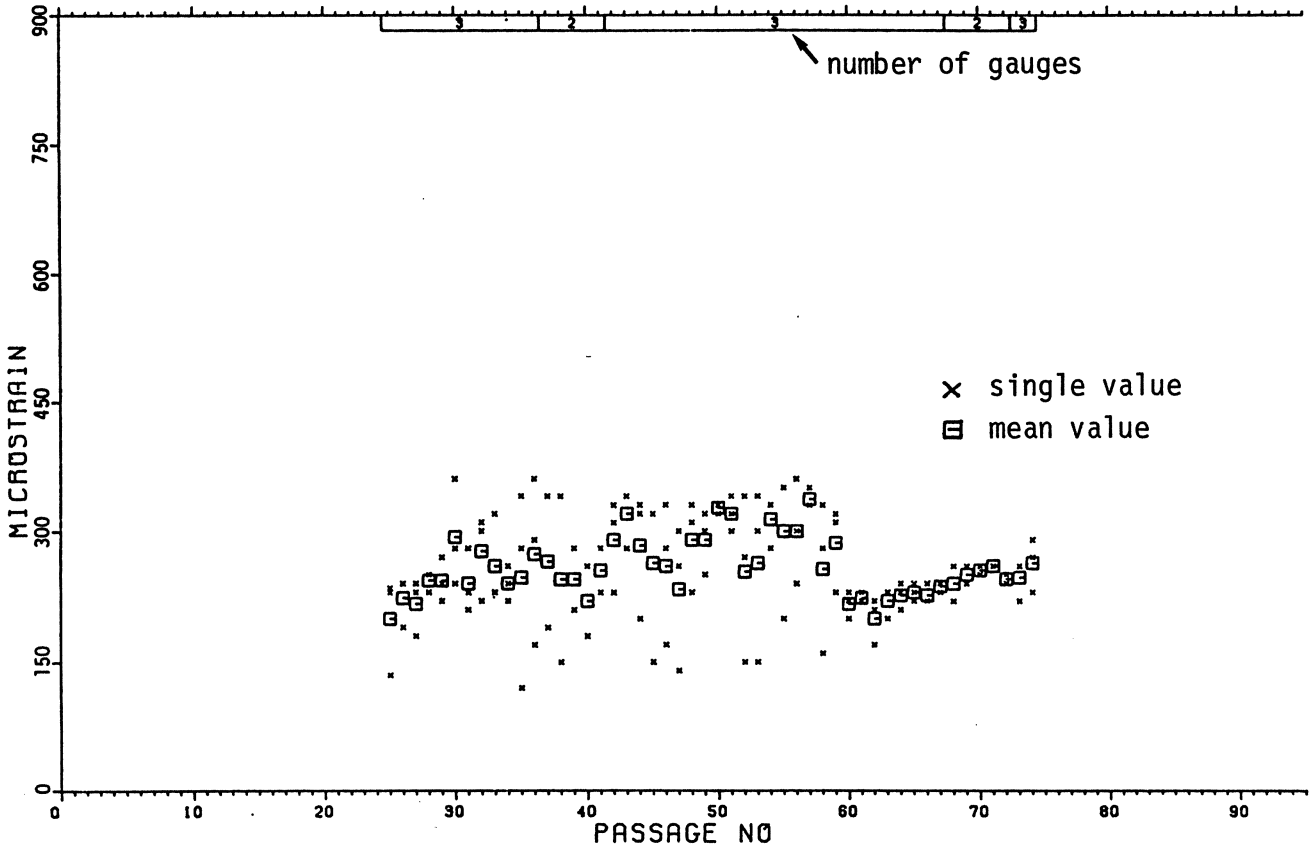
GAUGE GROUP 106-116-126-136

Type 3.1

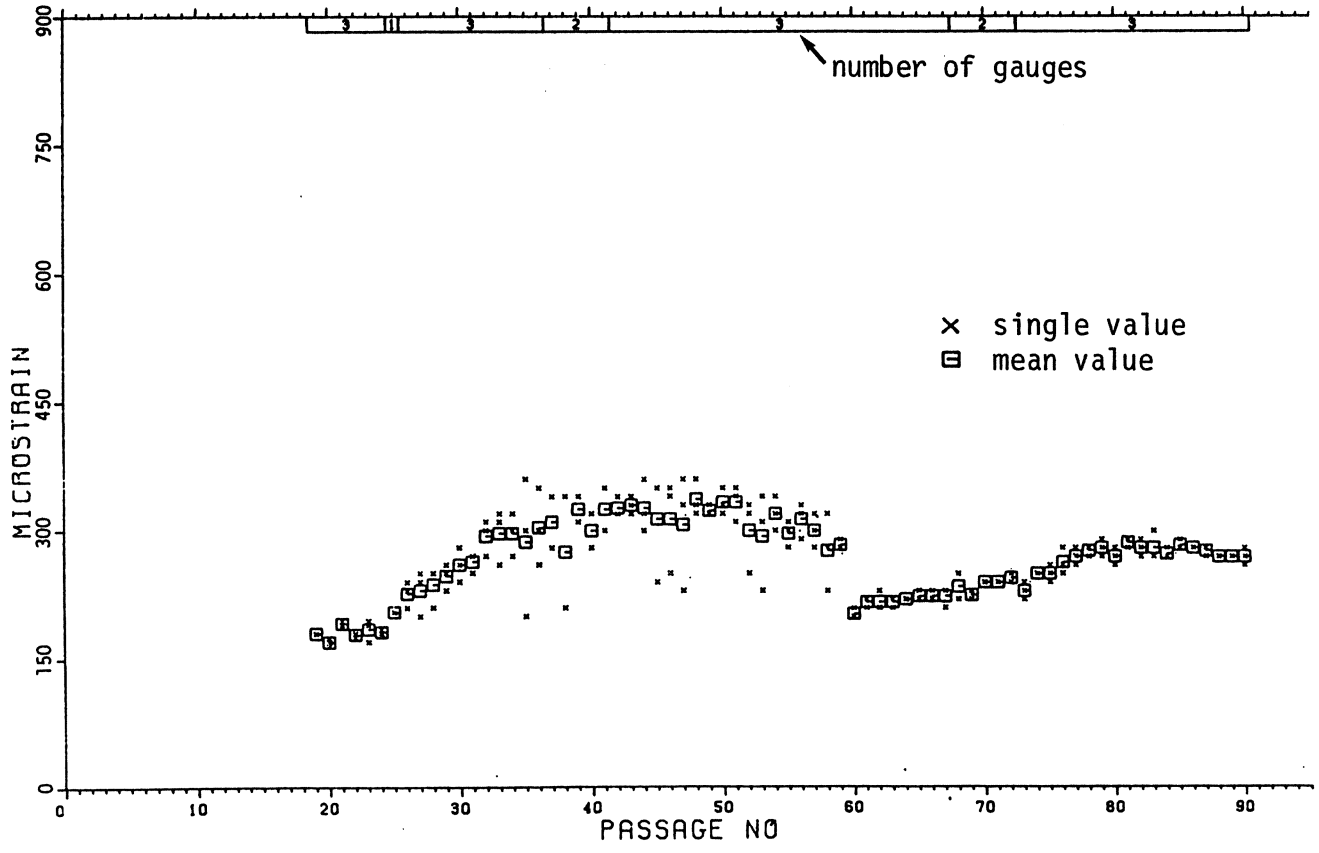


Team no. 2: STRAIN MEASUREMENTS RESULTS Annex B.6

GAUGE GROUP 101-111-121-131
Type 1.2

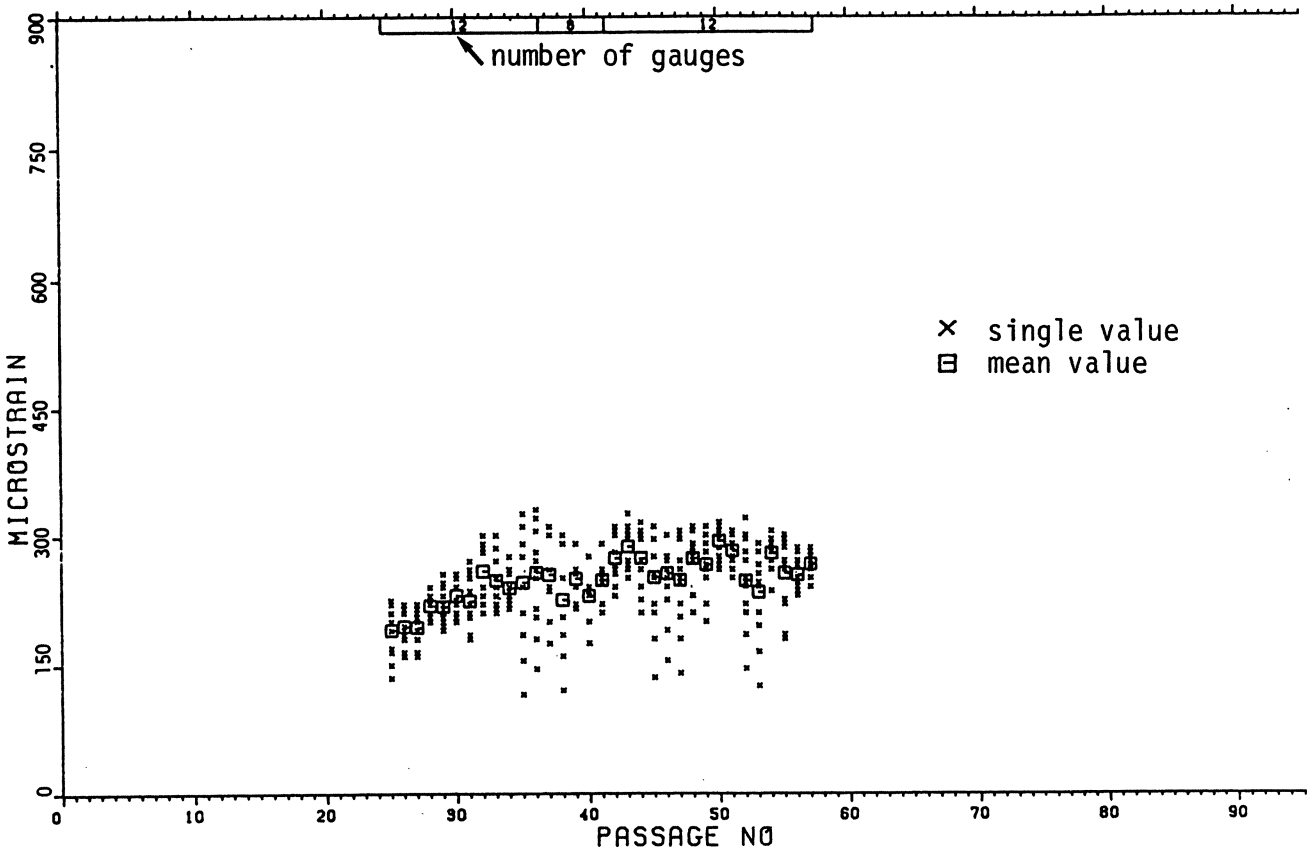


GAUGE GROUP 104-114-124-134
Type 1.2

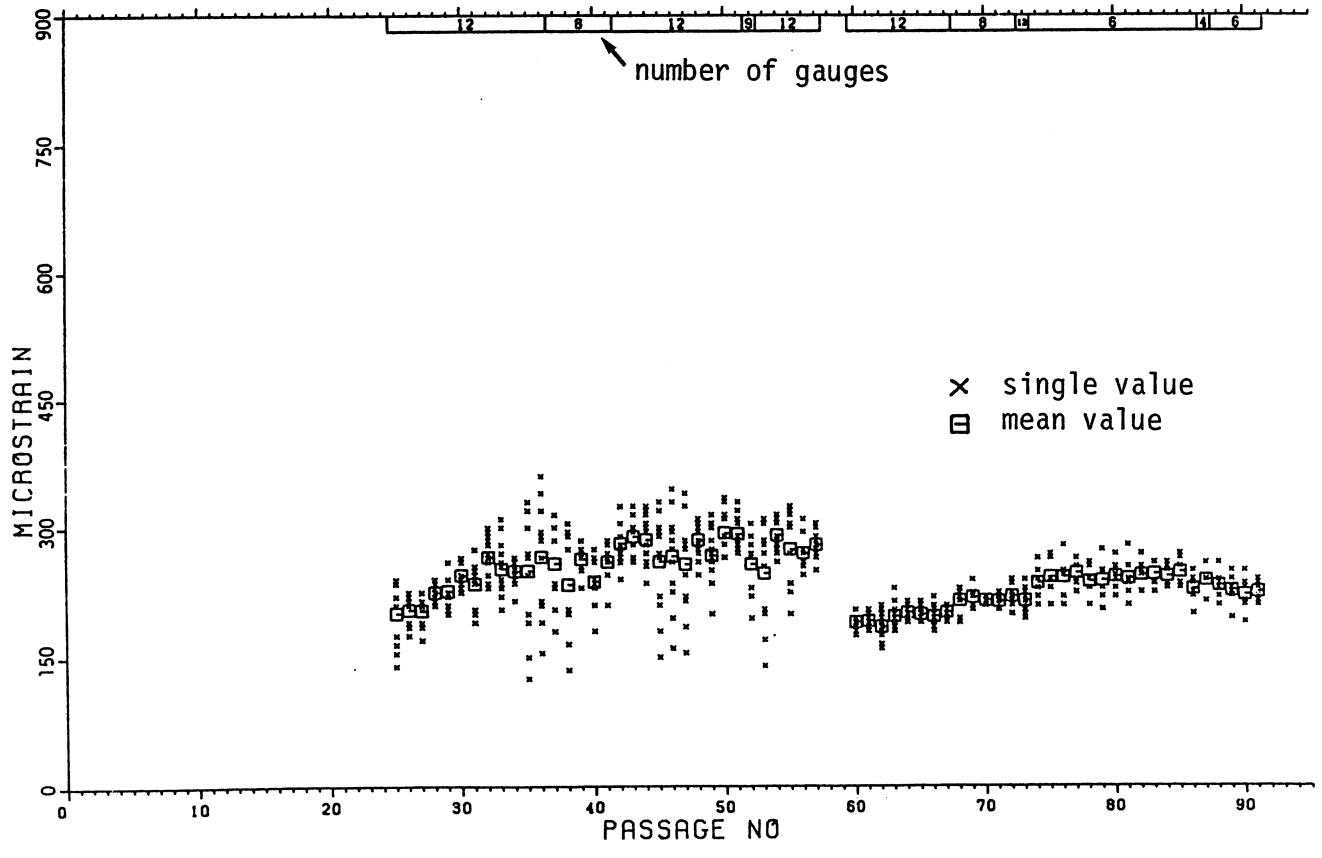


Team no. 3: STRAIN MEASUREMENTS RESULTS Annex B.7

GAUGE GROUP 101-111-121-131
Type 1.1

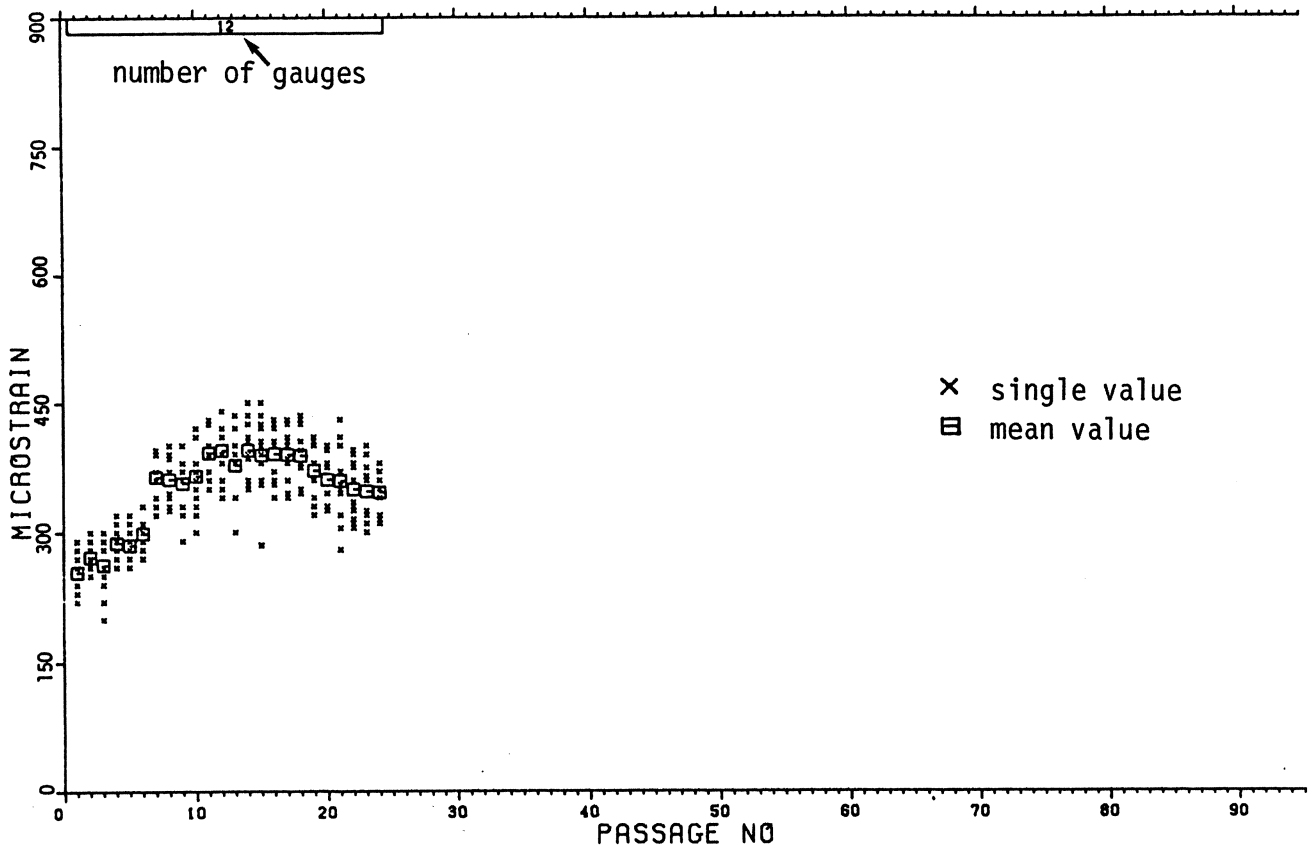


GAUGE GROUP 102-112-122-132
Type 1.1

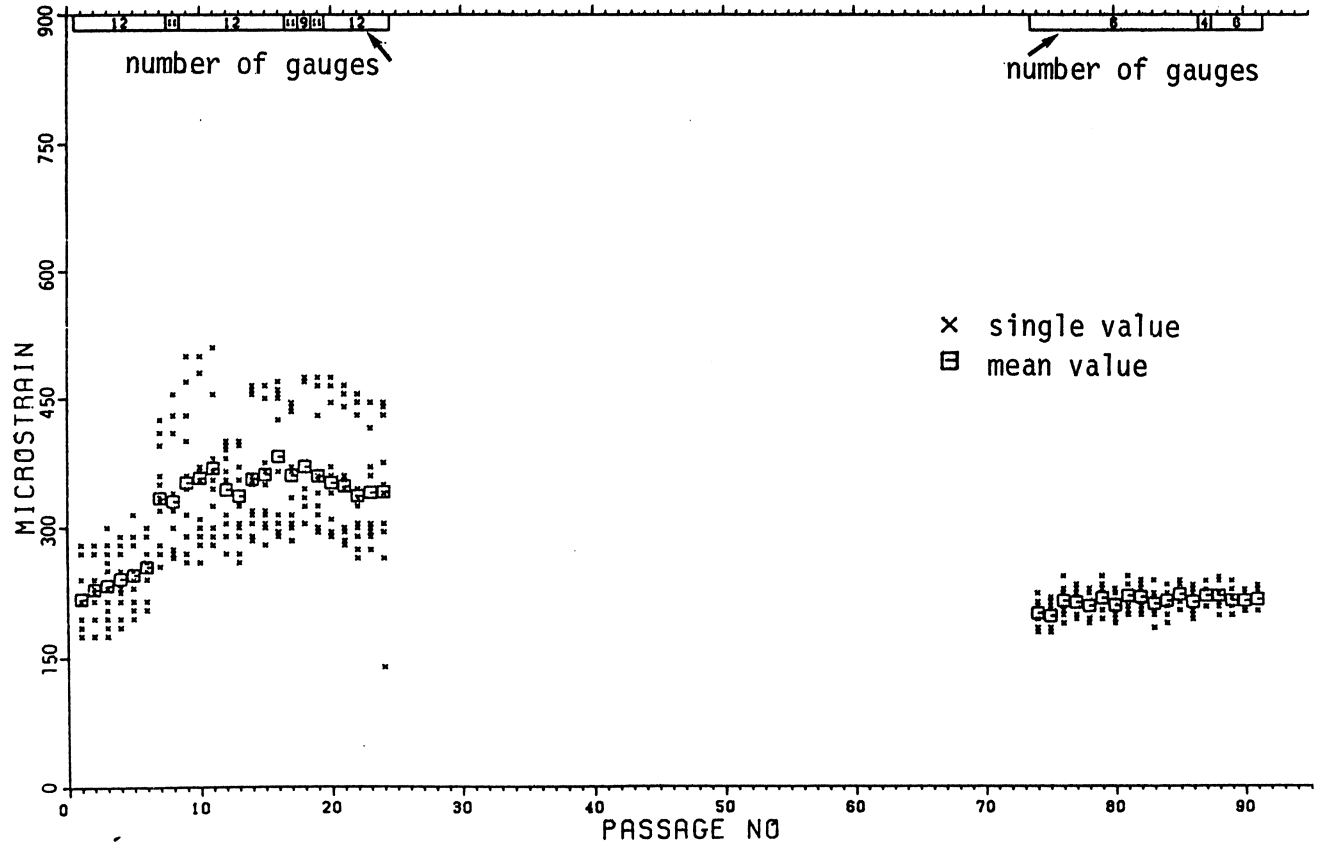


Team no. 3: STRAIN MEASUREMENTS RESULTS Annex B.8

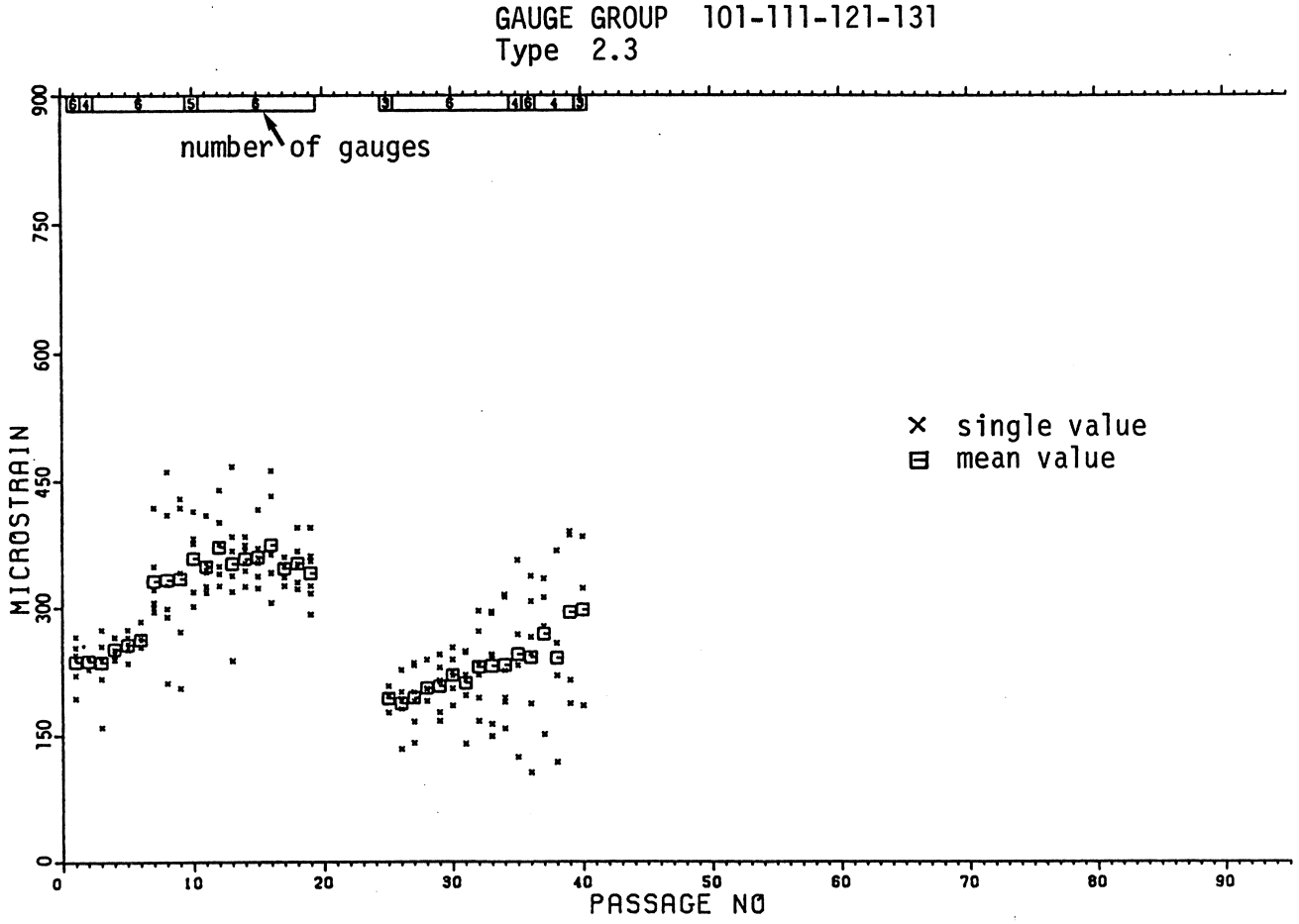
GAUGE GROUP 103-113-123-133
Type 1.1



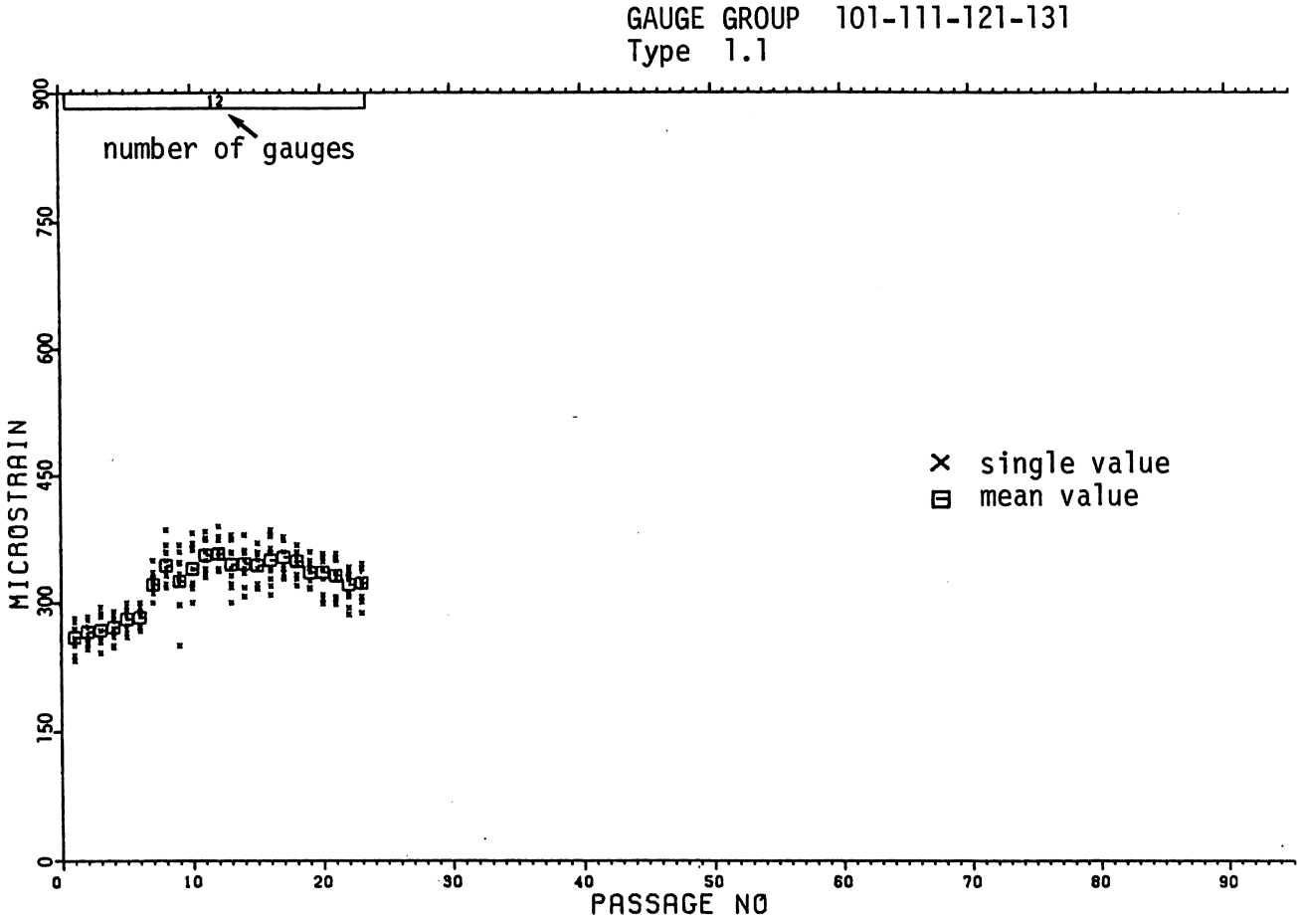
GAUGE GROUP 104-114-124-134
Type 3.1

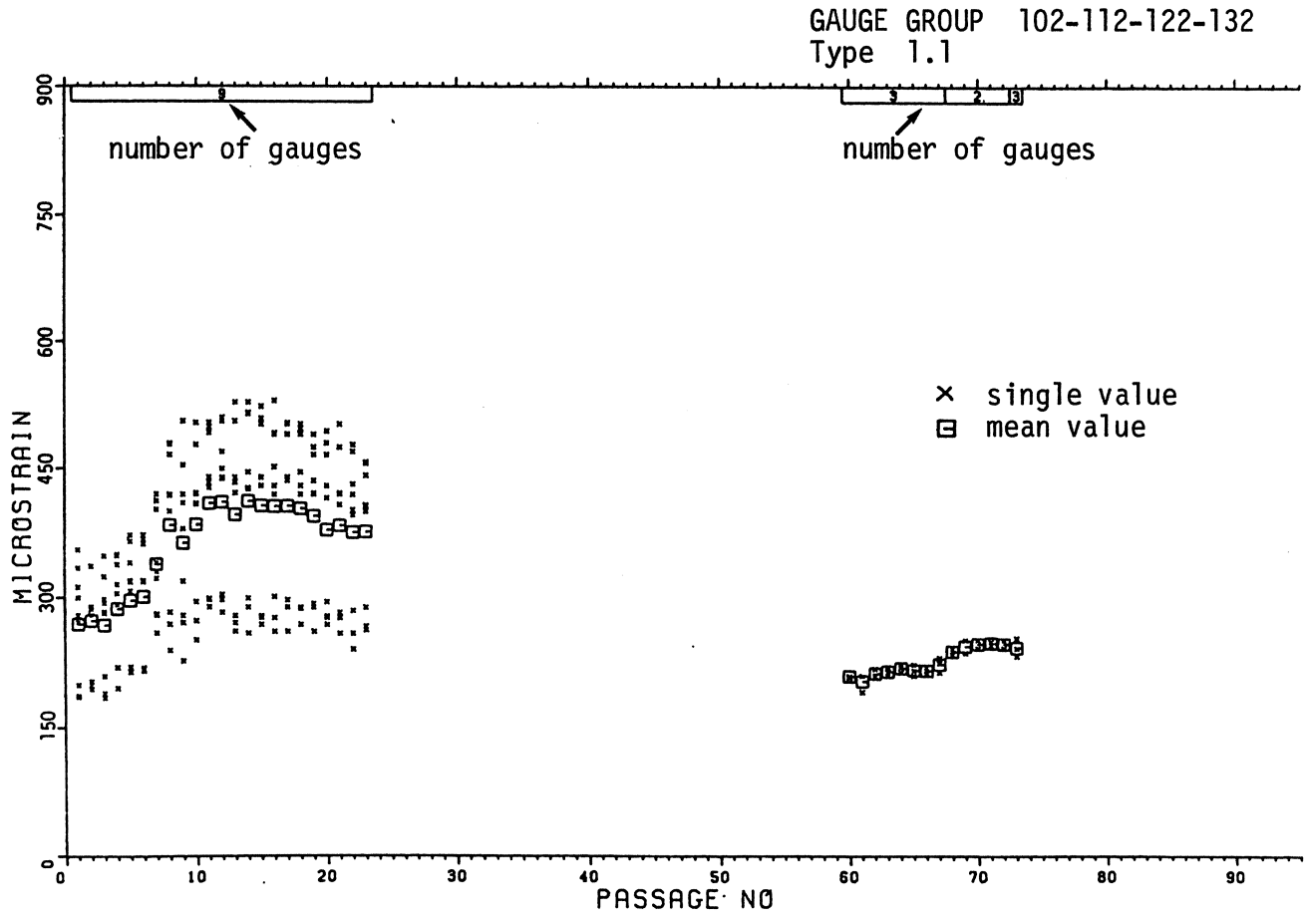


Team no. 4: STRAIN MEASUREMENTS RESULTS Annex B.9



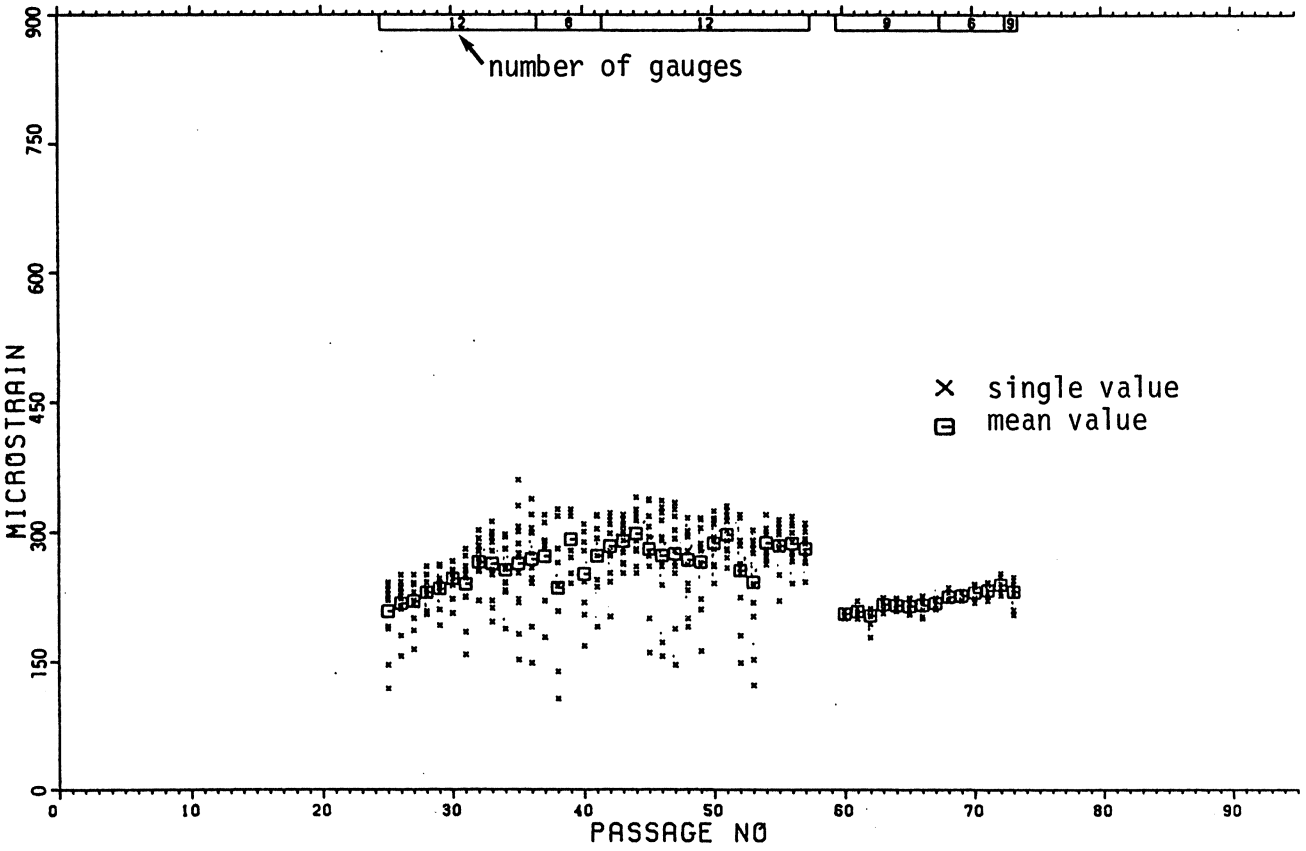
Team no. 5: STRAIN MEASUREMENTS RESULTS Annex B.10



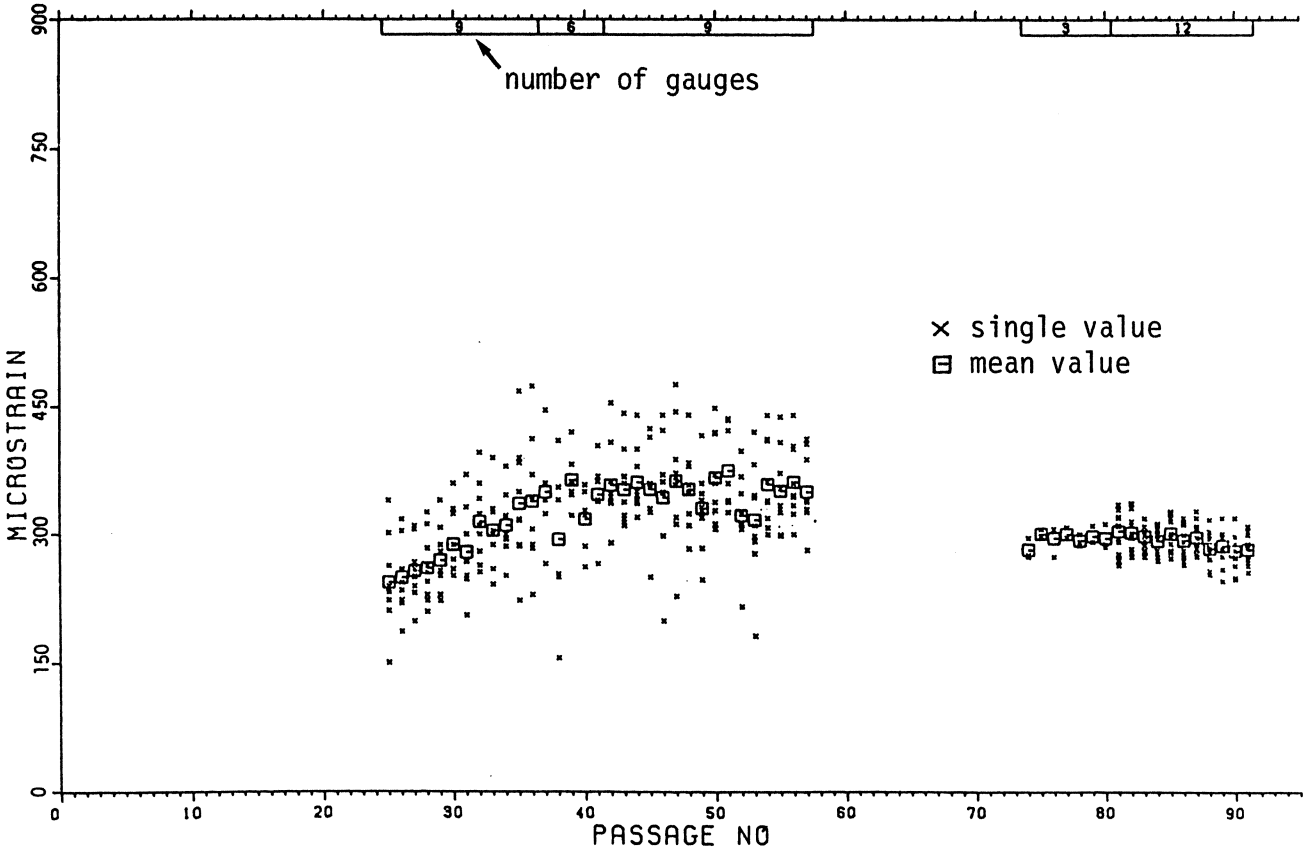


Team no. 5: STRAIN MEASUREMENTS RESULTS Annex B.11

GAUGE GROUP 103-113-123-133
Type 1.1

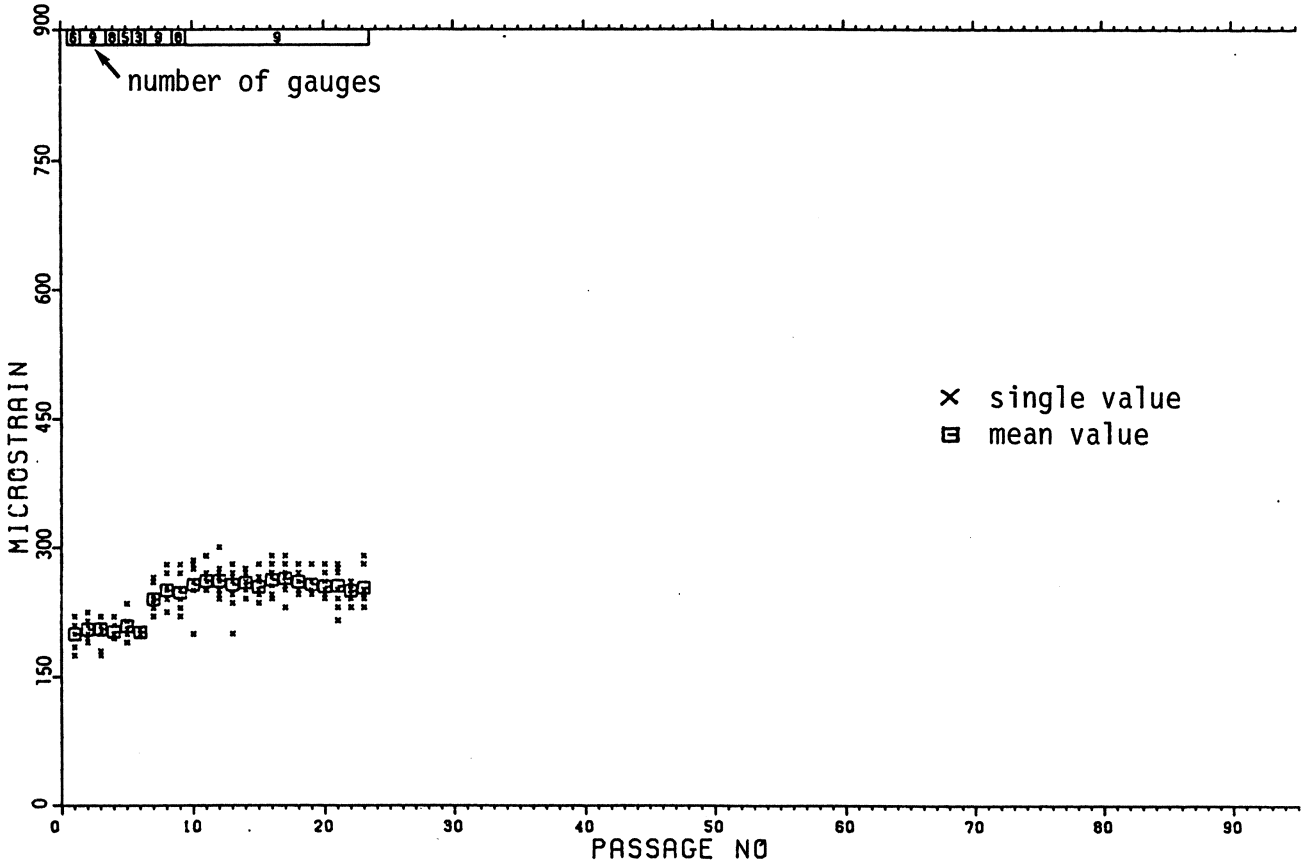


GAUGE GROUP 104-114-124-134
Type 1.1

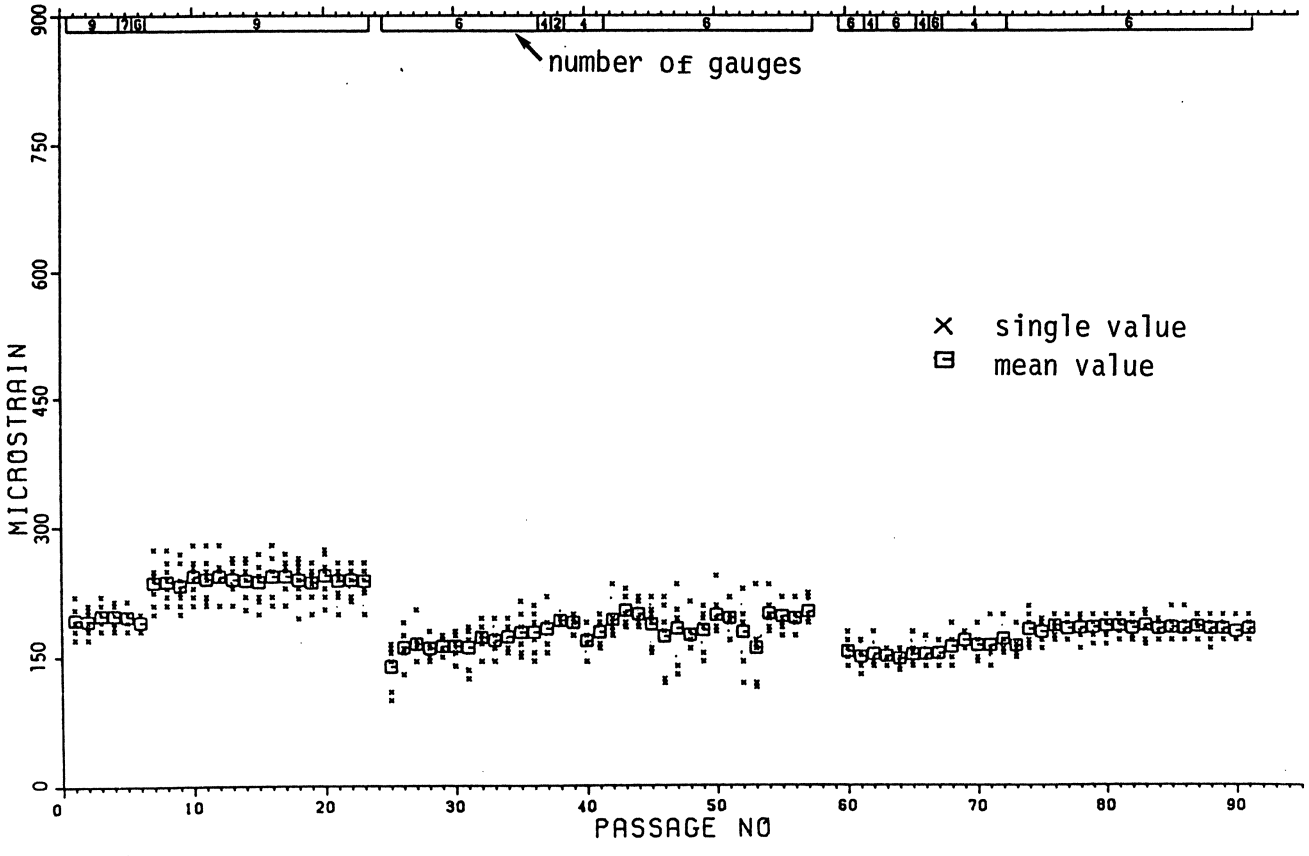


Team no. 6: STRAIN MEASUREMENTS RESULTS Annex B.12

GAUGE GROUP 101-111-121-131
Type 1.2

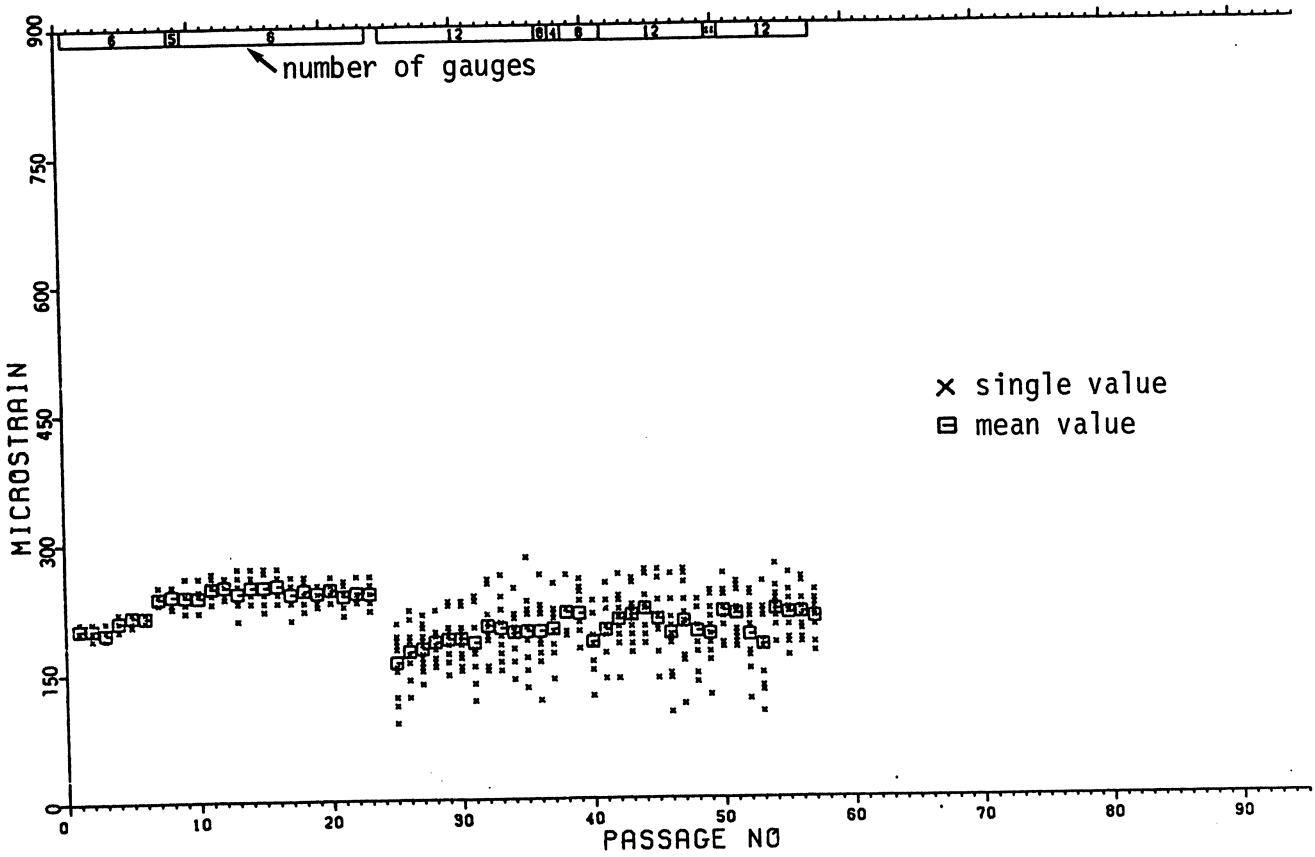


GAUGE GROUP 102-112-122-132
Type 1.2

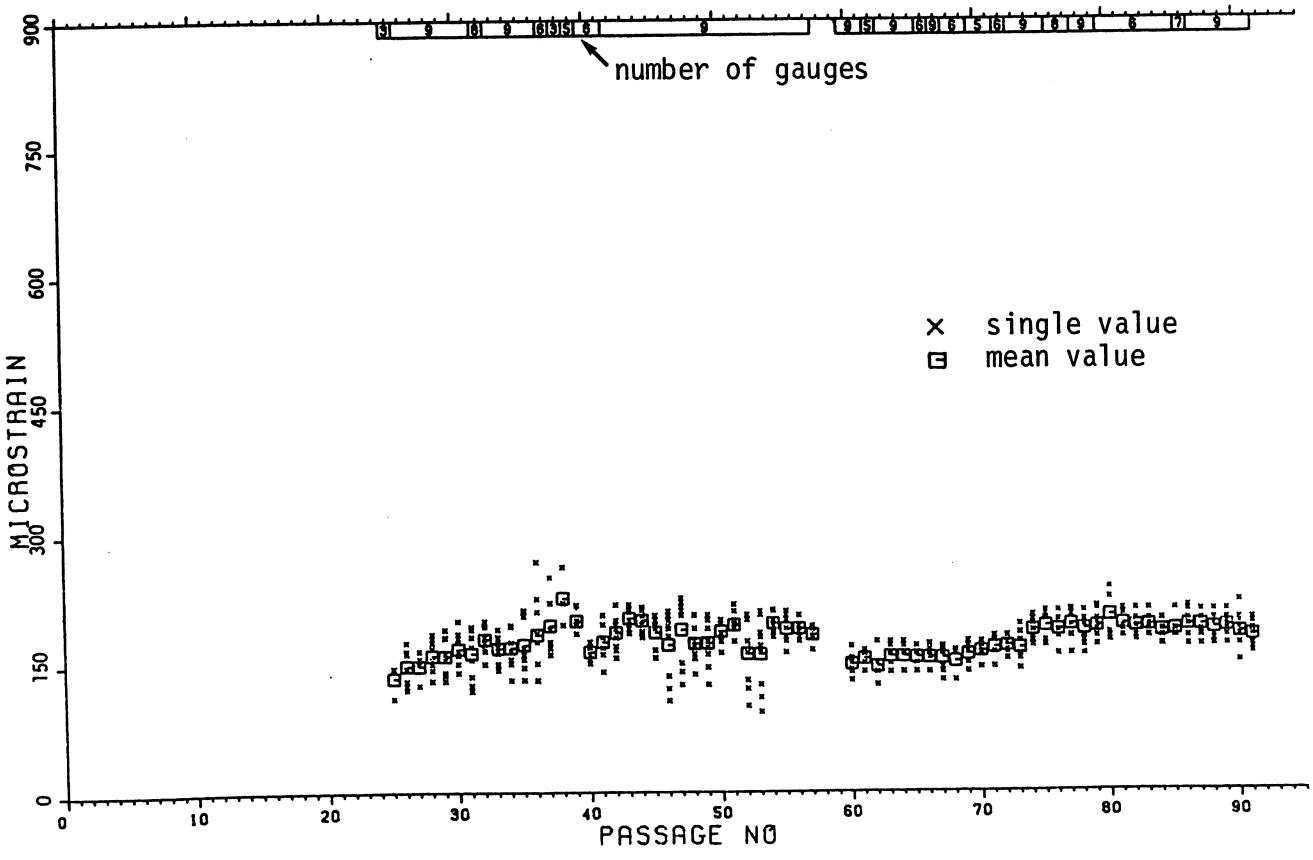


Team no. 6: STRAIN MEASUREMENTS RESULTS Annex B.13

GAUGE GROUP 103-113-123-133
Type 1.2

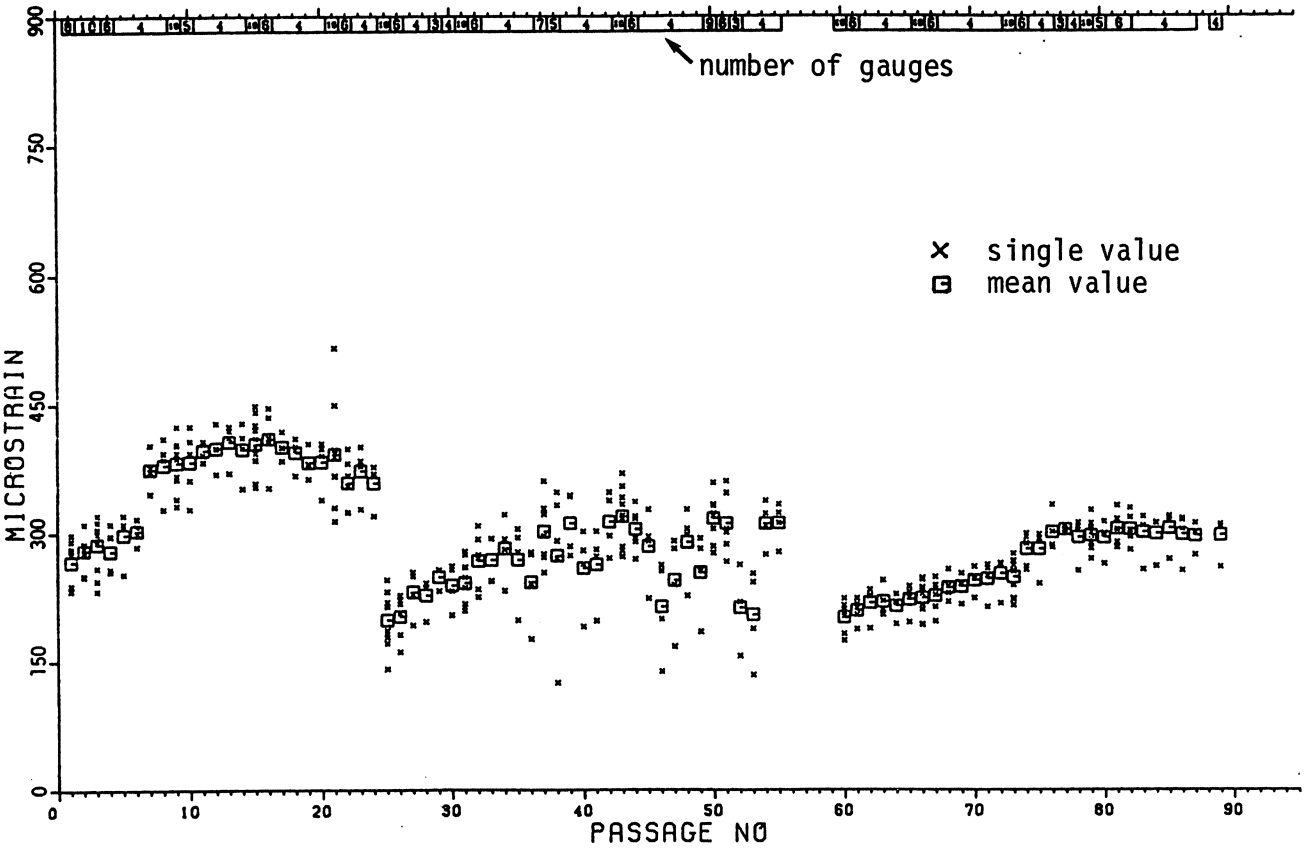


GAUGE GROUP 104-114-124-134
Type 1.2

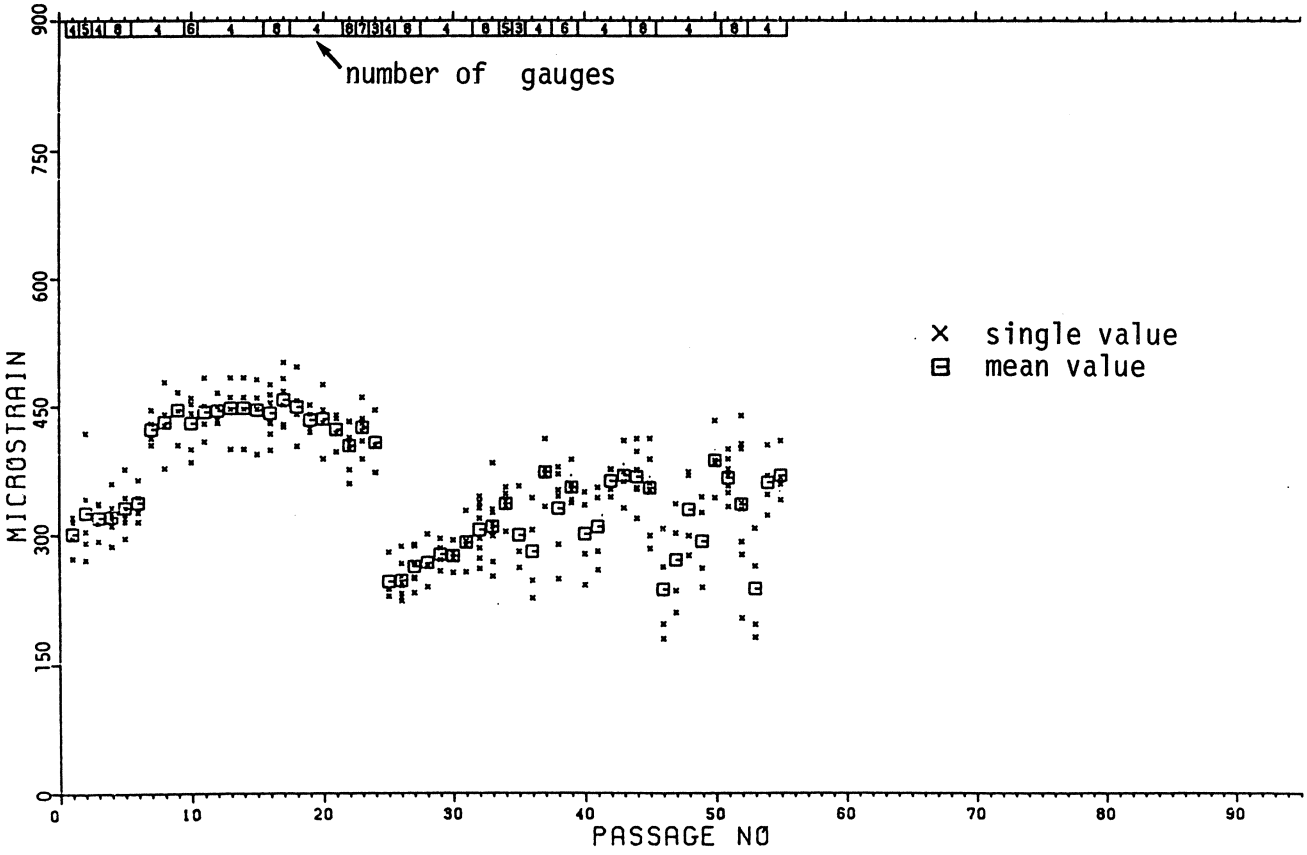


Team no. 7: STRAIN MEASUREMENTS RESULTS Annex B.14

GAUGE GROUP 101-111-121-131
Type 1.1

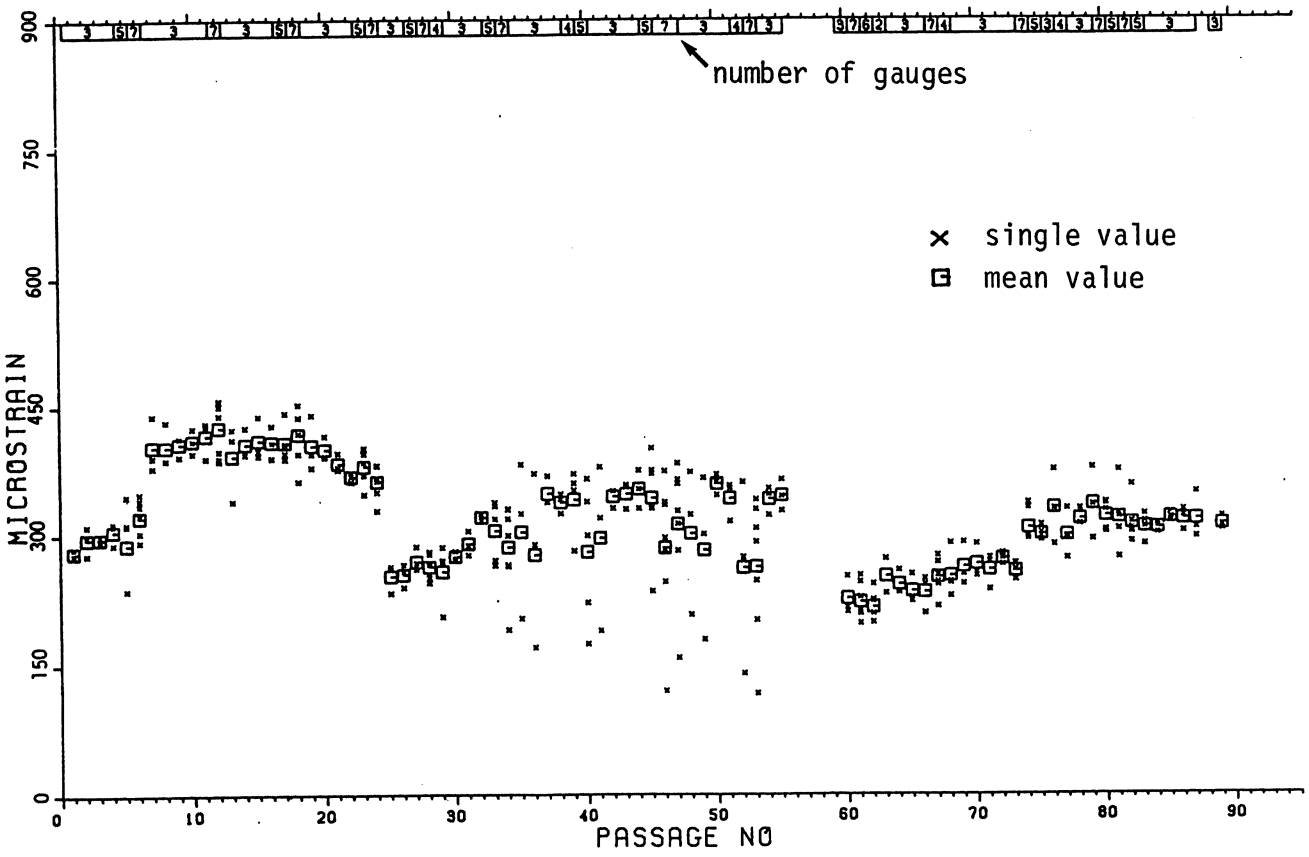


GAUGE GROUP 102-112-122-132
Type 1.1

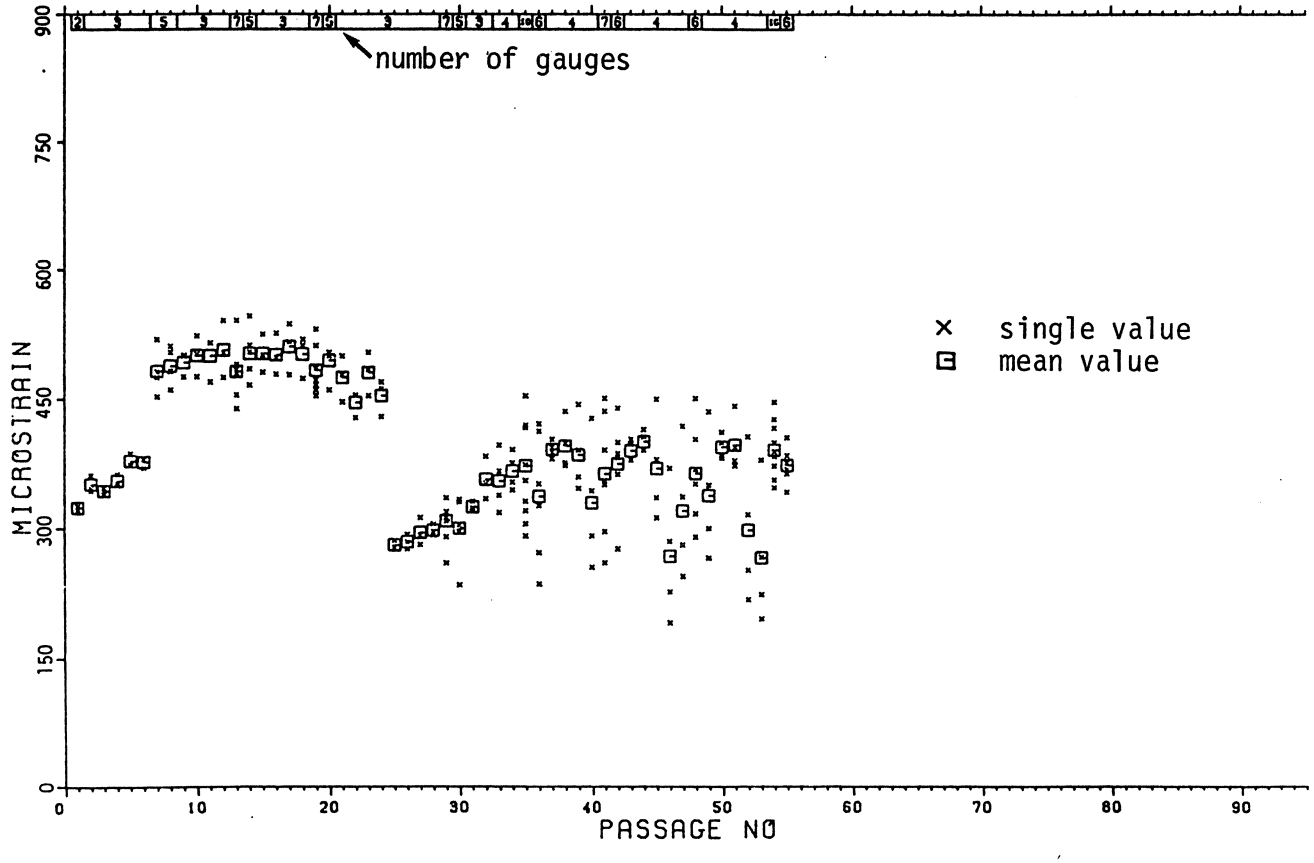


Team no. 7: STRAIN MEASUREMENTS RESULTS Annex B.15

GAUGE GROUP 103-113-123-133
Type 1.1

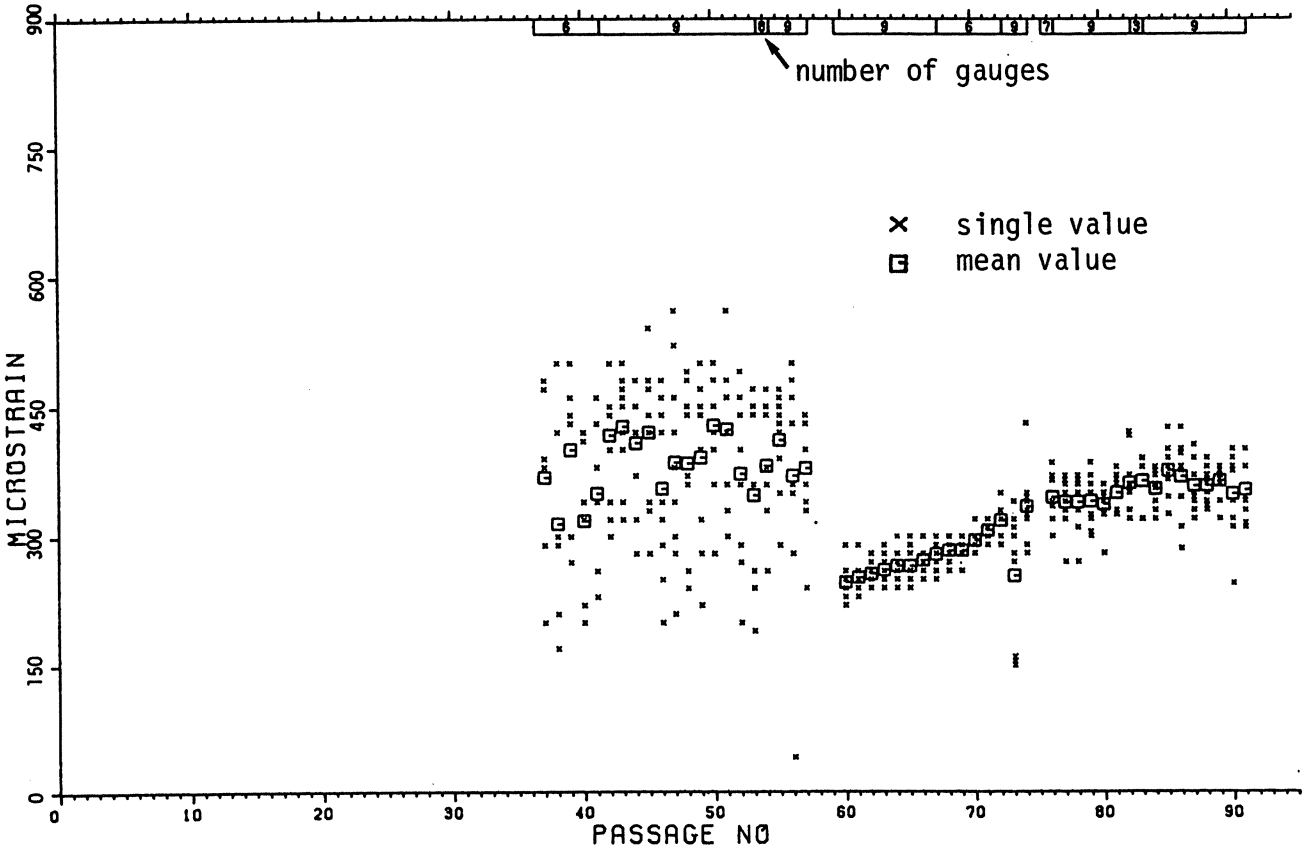


GAUGE GROUP 104-114-124-134
Type 1.1

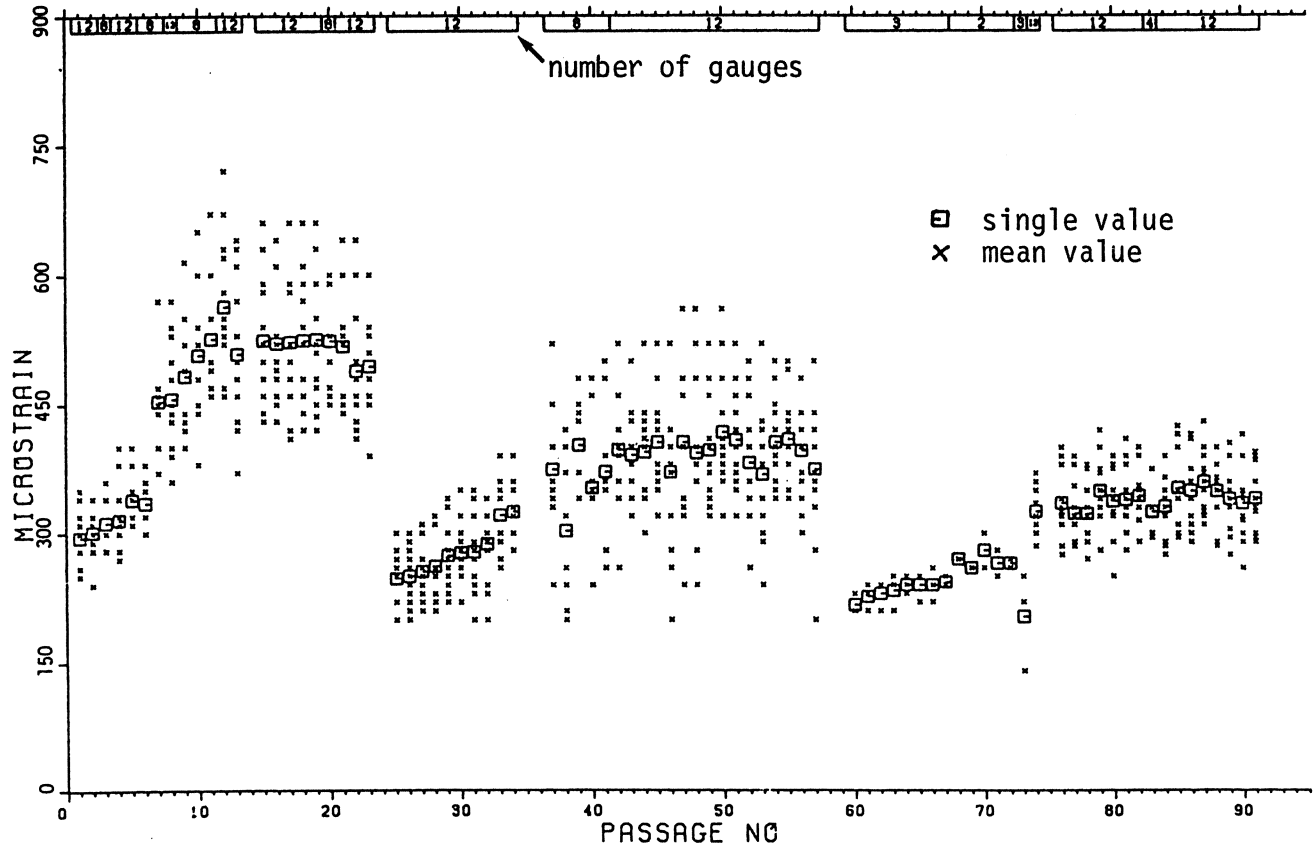


Team no. 8: STRAIN MEASUREMENTS RESULTS Annex B.16

GAUGE GROUP 101-111-121-131
Type 3.1

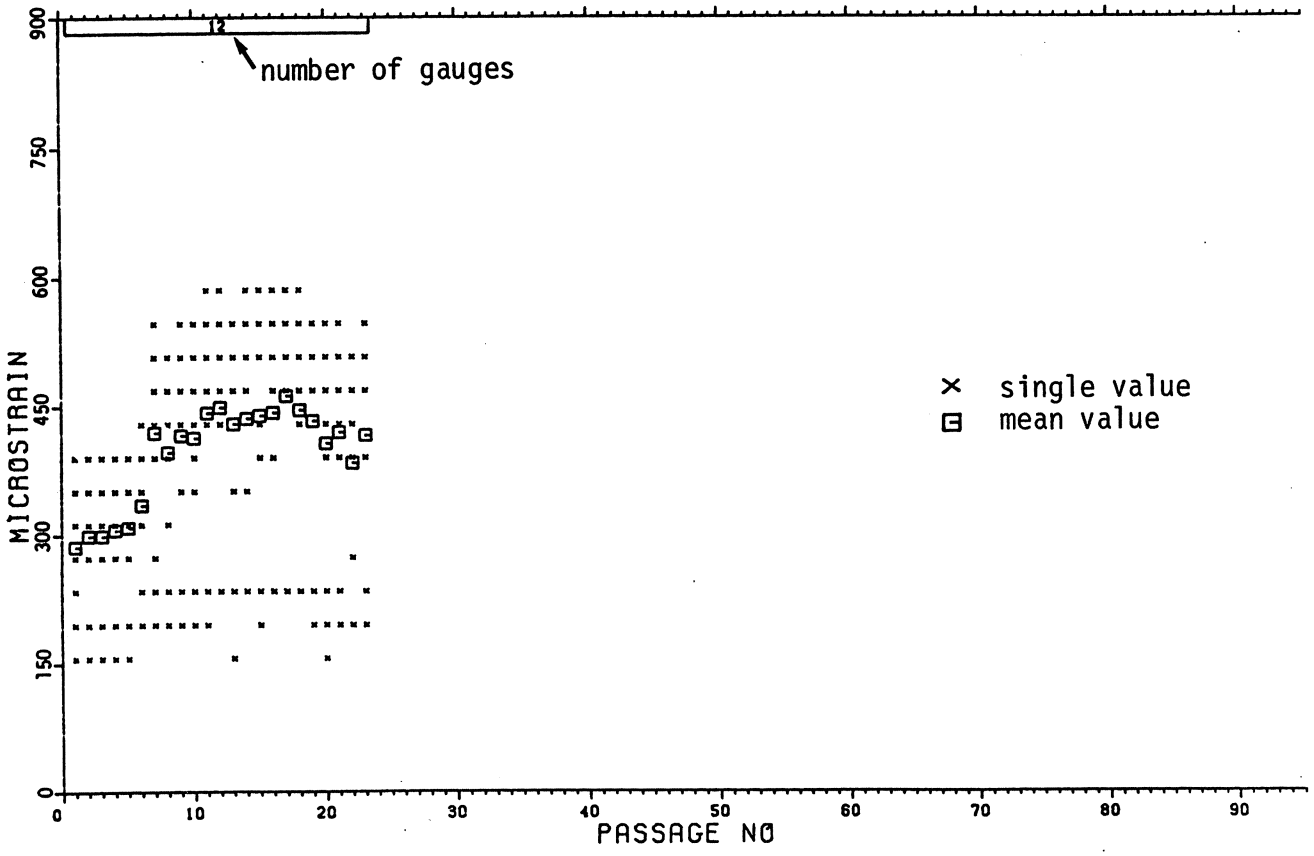


GAUGE GROUP 102-112-122-132
Type 3.1

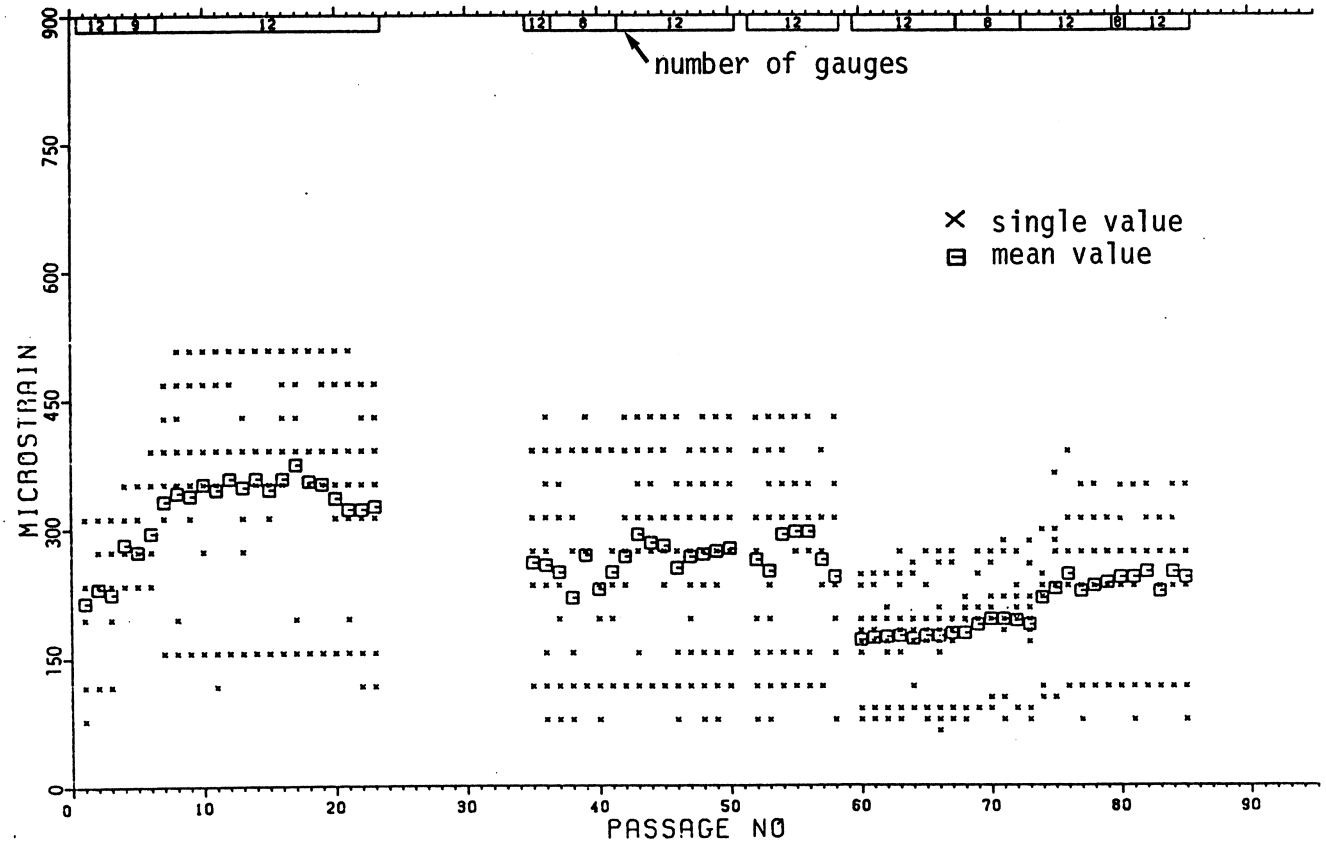


Team no. 9: STRAIN MEASUREMENTS RESULTS Annex B.17

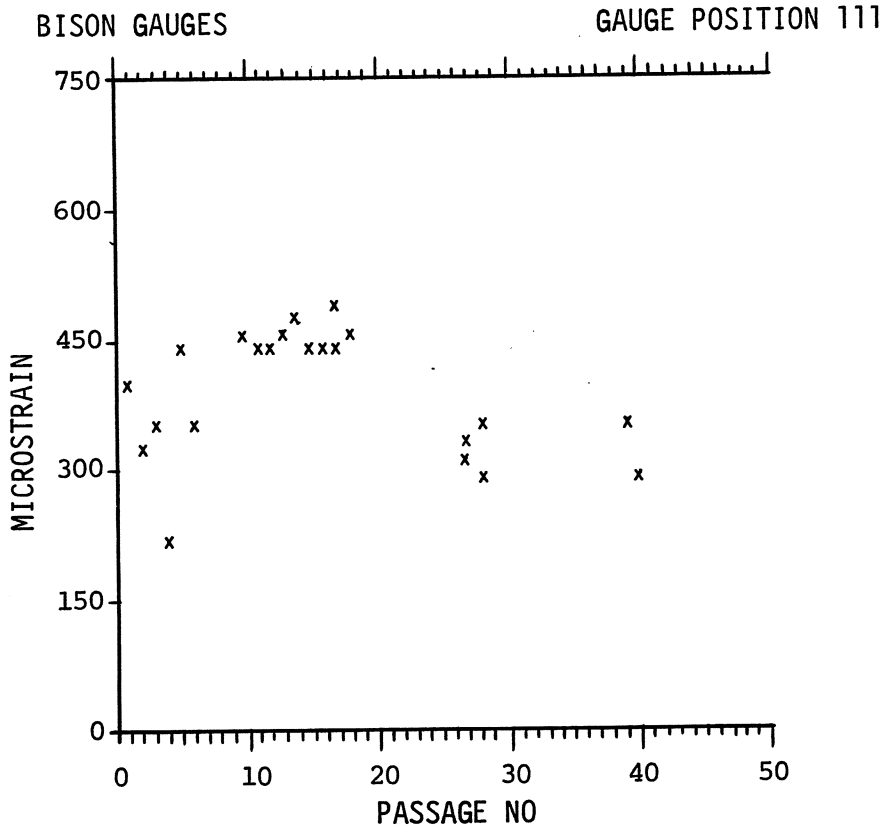
GAUGE GROUP 101-111-121-131
Type 2.2



GAUGE GROUP 102-112-122-132
Type 2.2



STRAIN MEASUREMENTS RESULTS



Passage Number	1	2	3	4	5	6	10	11	12	13	14	15	16	17	17	18	27	27	28	28	39	40
Vehicle	A	C	B	C	C	A	A	A	A	A	A	A	A	A	C	B	A	C	B	C	C	A
Tensile strain Axle 1 (μstrain)	223	-	357	-	-	312	312	401	401	357	446	379	379	357	223	580	290	-	223	178	312	268
Tensile strain Axle 2 (μstrain)	401	334	357	223	446	357	468	446	446	468	479	446	446	446	490	468	312	334	290	357	357	290

Annex C

CONSTRUCTION DETAILS OF THE STRAIN GAUGES

Annex C.1. Team 1, type 1.3 150
Annex C.2. Team 1, type 2.1 151
Annex C.3. Team 1, type 3.1 152
Annex C.4. Team 2, type 1.2 153
Annex C.5. Team 3, type 1.1 and 3.1. 154
Annex C.6. Team 4, type 2.3 155
Annex C.7. Team 5, type 1.1 156
Annex C.8. Team 6, type 1.2 157
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Annex C.10. Team 8, type 2.1 159
Annex C.11. Team 9, type 2.2 160

Annex C.1

INQUIRY ON GAUGES
ENQUETE SUR LES CAPTEURS

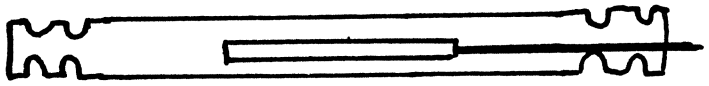
1. Team : No 1
   Equipe :

2. Type of gauge : DA 3
   Type de capteur :

3. Manufacture : Hottinger Baldwin Mess. HBM
   Fabricant :

   Supplier :
   Fournisseur :

4. Schematic drawing (plan and profiles)
   Schéma d'utilisation (plan et coupes)



No protection

5. Use (number, years, loss-rate):
   Utilisation (nombre, années, pertes):

6. Cost : 180 $
   Coût

7. Accuracy (theoretical) :
   Précision (théorique) :

8. Cables specification : HBM - MOD 5004 - Ø 0.17 x 4
   Câbles : PVC PROTECTION - 0.40 p Farad/m

9. Comments :
   Commentaires :

Annex C.2

INQUIRY ON GAUGES
ENQUETE SUR LES CAPTEURS

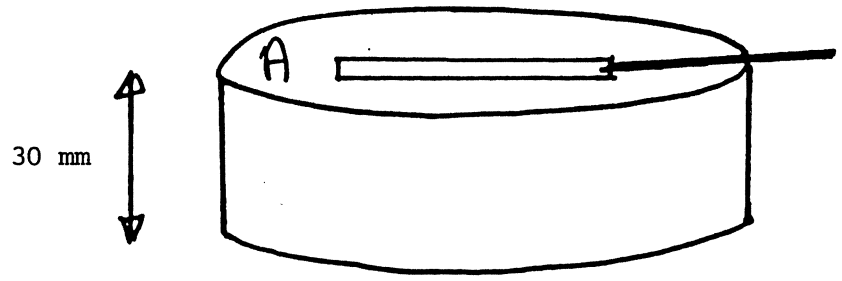
1. Team : No 1
   Equipe :

2. Type of gauge : LP 21 60 - 120 on asphalt concrete specimens
   Type de capteur : obtained from Marshall specimens

3. Manufacture : Hottinger Baldwin Mess. HBM
   Fabricant :

   Supplier :
   Fournisseur :

4. Schematic drawing (plan and profiles)
   Schéma d'utilisation (plan et coupes)



Face A at the base of the asphalt layer - Strain gauges protected by HBM X 60 glue

5. Use (number, years, loss-rate): 60, 10 years, loss-rate:
   Utilisation (nombre, années, pertes) from 0 to 40%

6. Cost (of the strain gauge) : 12 $
   Coût :

7. Accuracy (theoretical) :
   Précision (théorique) :

8. Cables specification : HBM - MOD 5004 - Ø 0.17 x 4
   Câbles : PVC PROTECTION - 0.40 p Farad/m

9. Comments :
   Commentaires :

Annex C.3

INQUIRY ON GAUGES
ENQUETE SUR LES CAPTEURS

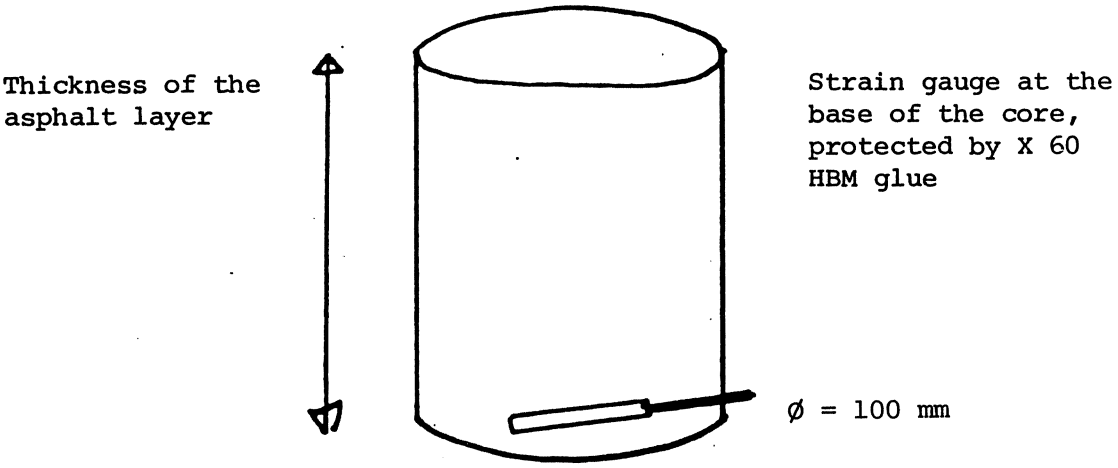
1. Team : No 1
   Equipe :

2. Type of gauge : LP 21 60 - 120
   Type de capteur :

3. Manufacture : Hottinger Baldwin Mess. HBM
   Fabricant :

   Supplier :
   Fournisseur :

4. Schematic drawing (plan and profiles)
   Schéma d'utilisation (plan et coupes)



5. Use (number, years, loss-rate) : 100, 8 years, 0%
   Utilisation (nombre, années, pertes) :

6. Cost : 20 $
   Coût :

7. Accuracy (theoretical):
   Précision (théorique) :

8. Cables specification : HBM - MOD 5004 - Ø 0.17 x 4
   Câbles : PVC PROTECTION - 0.40 p Farad/m

9. Comments :
   Commentaires :

Annex C.4

INQUIRY ON GAUGES
ENQUETE SUR LES CAPTEURS

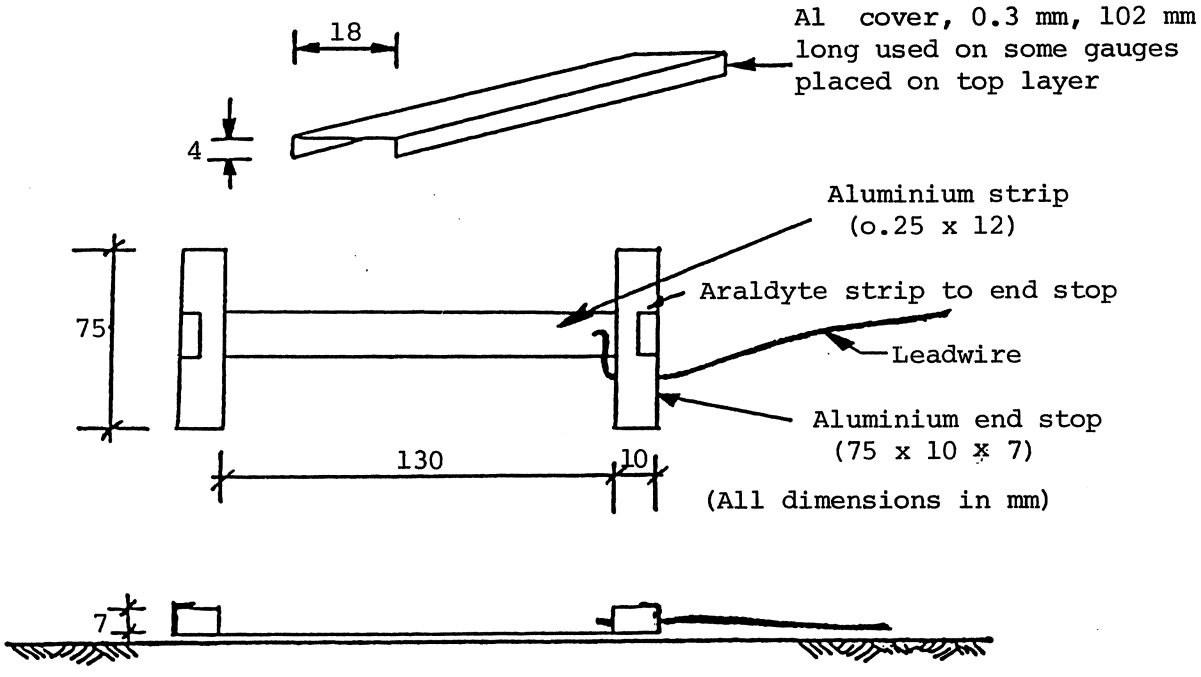
1. Team : No 2
   Equipe :

2. Type of gauge : Kyowa wire 120 ohm strain gauge KC-70-A1-11
   Type de capteur : bonded to 0.25 mm thick x 12 mm wide Aluminium strip with end stops.

3. Manufacture : Kyowa, Japan
   Fabricant :

   Supplier : Townson & Mercer, Box 378, Glen Haverley 3150,
   Fournisseur : Australia

4. Schematic drawing (plan and profiles)
   Schéma d'utilisation (plan et coupes)



5. Use (number, years, loss-rate) : In 1981, 319 gauges were in-
   Utilisation (nombre, années, pertes) : stalled. 50% of these survided material compaction.

6. Cost (US $) : $ 40 Aust. each (approx. $ 35 US)
   Coût :

7. Acciracy (theoretical) : ?
   Précision (théorique)

8. Cables specification : Australian Standard Cable 71TK3.501. 3 core
   Câbles : twisted with shield. PVC coated

9. Comments : Recording equipment used supplied by Autostrade, Italy.
   Commentaires : Recording of data performed by Autostrade.

Annex C.5

INQUIRY ON GAUGES
ENQUETE SUR LES CAPTEURS

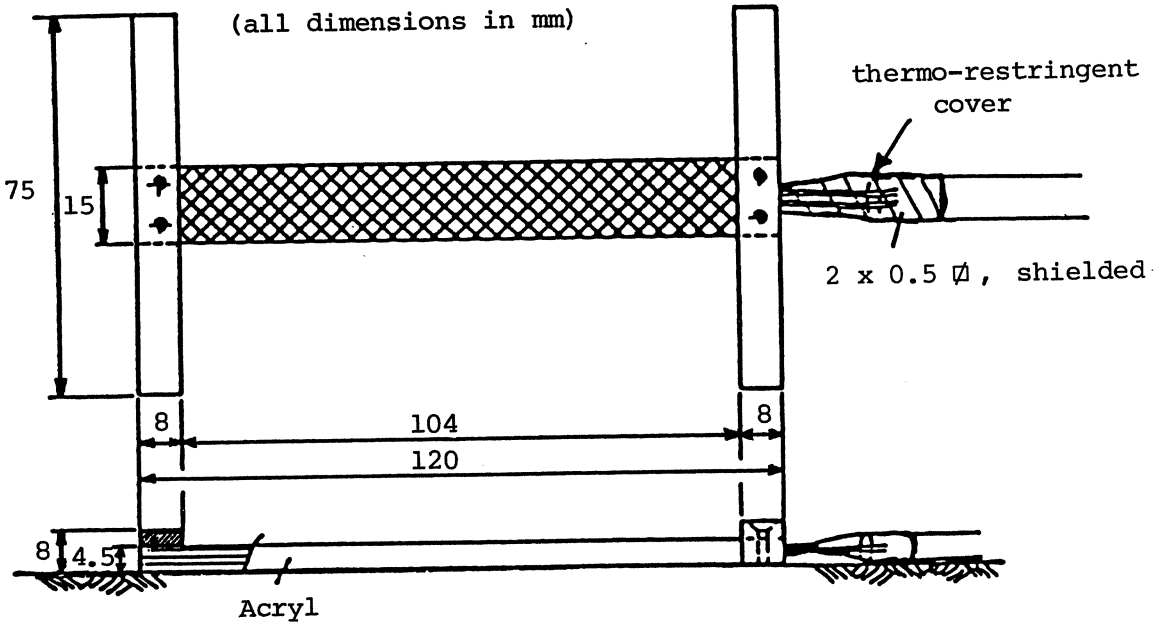
1. Team : No 3
   Equipe :

2. Type of gauge : 1) KYOWA KM - 120 - H2 - 11 L 100-3 (Type 1.1)
   Type de capteur : 2) HBM 60/600 LP 61 (Type 3.1, glued on cores)

3. Manufacture : 1) KYOWA - Japan
   Fabricant : 2) Hottinger Baldwin Messtechnik - Germany

   Supplier : 1) Traco AG - Zürich (CH)
   Fournisseur : 2) Schenk AG - Nanikon + Yverdon (CH)

4. Schematic drawing (plan and profiles) : KYOWA (k = 2.00)
   Schéma d'utilisation (plan coupes)



5. Use (number, years, loss-rate) : KYOWA: 100 since 4 years;
   Utilisation (nombre, années, pertes) : Losses between 15 and 30 %

6. Cost (US $) : 1) KYOWA gauge ∿40 US$ (material and labour)
   Coût : 2) HBM gauge ∿15 US$ (gauge only)

7. Accuracy (theoretical) :
   Précision (théorique) :

8. Cables specification : shielded cables type 2546 F 2 x 0.40 mm^2
   Câbles :

9. Comments : -
   Commentaires :

Annex C.6

INQUIRY ON GAUGES
ENQUETE SUR LES CAPTEURS

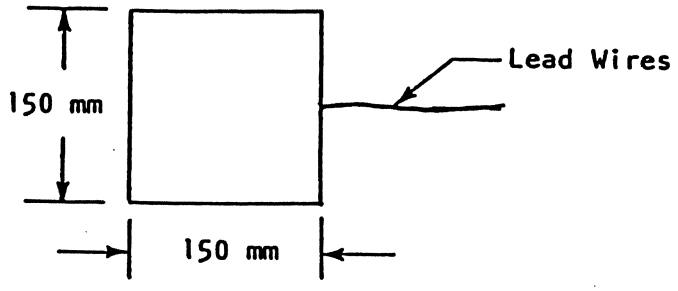
1. Team : No 4
   Equipe :

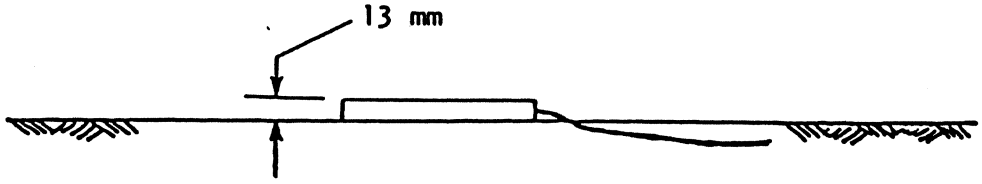
2. Type of gauge : Metal Foil Gauge, Asphalt Embedded
   Type de capteur :

3. Manufacture : Micro-Measurements, U.S.A.
   Fabricant :

   Supplier : Intertechnology Limited, Canada
   Fournisseur :

4. Schematic drawing (plan and profiles)
   Schéma d'utilisation (plan et coupes)





5. Use (number, years, loss-rate) : : 60 pieces / 1973 - 1984
   Utilisation (nombre, années, pertes) : 22% Loss

6. Cost (US $) : Gauge cost only - $ 15.00 Can
   Coût :

7. Accuracy (theoretical) : Dependent on recording process,
   Précision (théorique) : Typically 1 X 10^{-6}

8. Cables specification : Belden 8434, 2 Pair, each shielded
   Câbles :

9. Comments : Service life unknown, gauges still operational
   Commentaires : since 1973

Annex C.7

INQUIRY ON GAUGES
ENQUETE SUR LES CAPTEURS

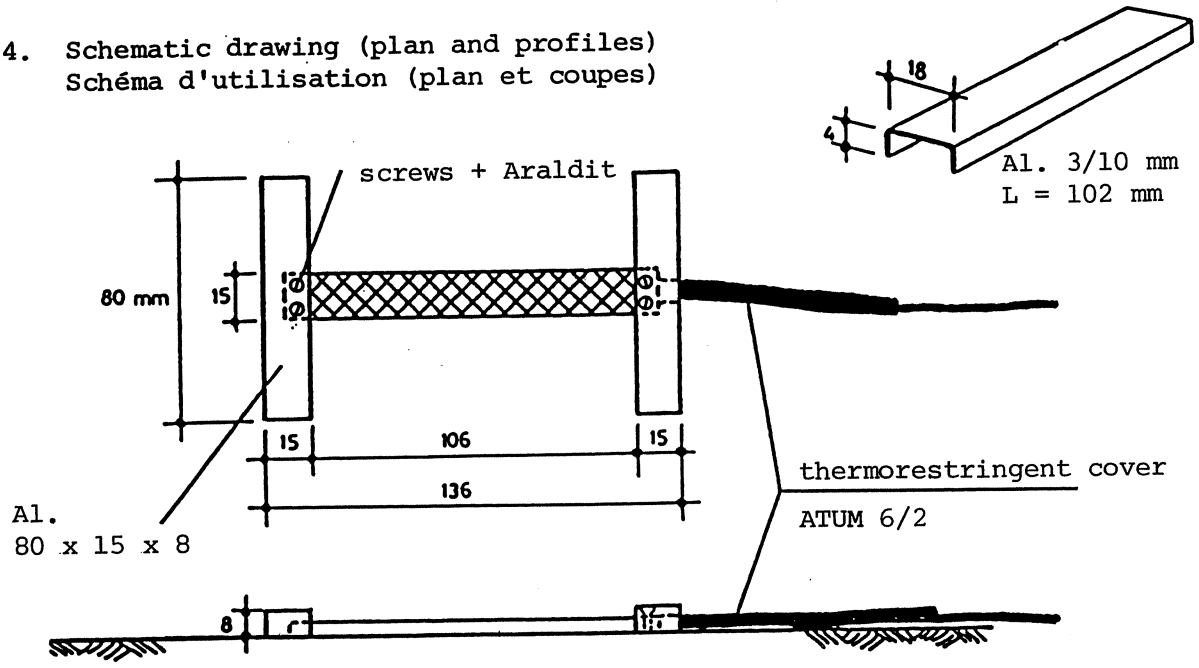
1. Team : No 5
   Equipe

2. Type of gauge : KYOWA KM-120-H2-11 L100-3
   Type de capteur : (strain gauge embedded in acryl, modulus)

3. Manufacture : KYOWA - Japan
   Fabricant :

   Supplier : TRACO ELECTRONIC AG - 8002 Zürich
   Fournisseur :

4. Schematic drawing (plan and profiles)
   Schéma d'utilisation (plan et coupes)



5. Use (number, years, loss-rate) : 80 pieces since 1980, 40 % losses
   Utilisation (nombre, années, pertes):

6. Cost (US $) : 35 $
   Coût :

7. Accuracy (theoretical): unknown
   Précision (théorique) :

8. Cables specification : colorflex CY 2 x 0,25 mm^2, shielded
   Câbles :

9. Comments : -
   Commentaires :

Annex C.8

INQUIRY ON GAUGES
ENQUETE SUR LES CAPTEURS

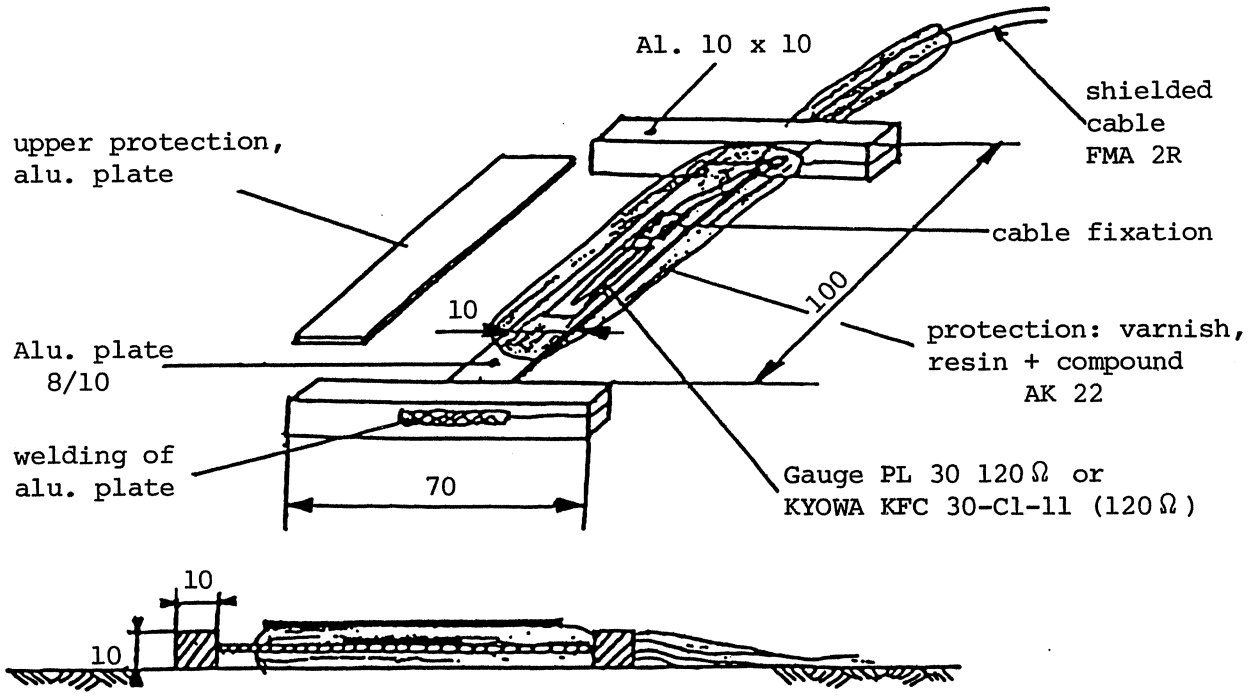
1. Team : No 6
   Equipe :

2. Type of gauges :
   Type de capteur :

3. Manufacture : L.C.P.C (Section Mécanique des Chaussées)
   Fabricant :

   Supplier :
   Fournisseur :

4. Schematic drawing (plan and profiles)
   Schéma d'utilisation (plan et coupes)



5. Use (number, years, loss-rate) :
   Utilisation (nombre, années, pertes) :

6. Cost (US $) : 23 $
   Coût :

7. Accuracy (theoretical) :
   Précision (théorique) :

8. Cables specification : FM 1R and FM 2R
   Câbles :

9. Comments :
   Commentaires :

Annex C.9

INQUIRY ON GAUGES
ENQUETE SUR LES CAPTEURS

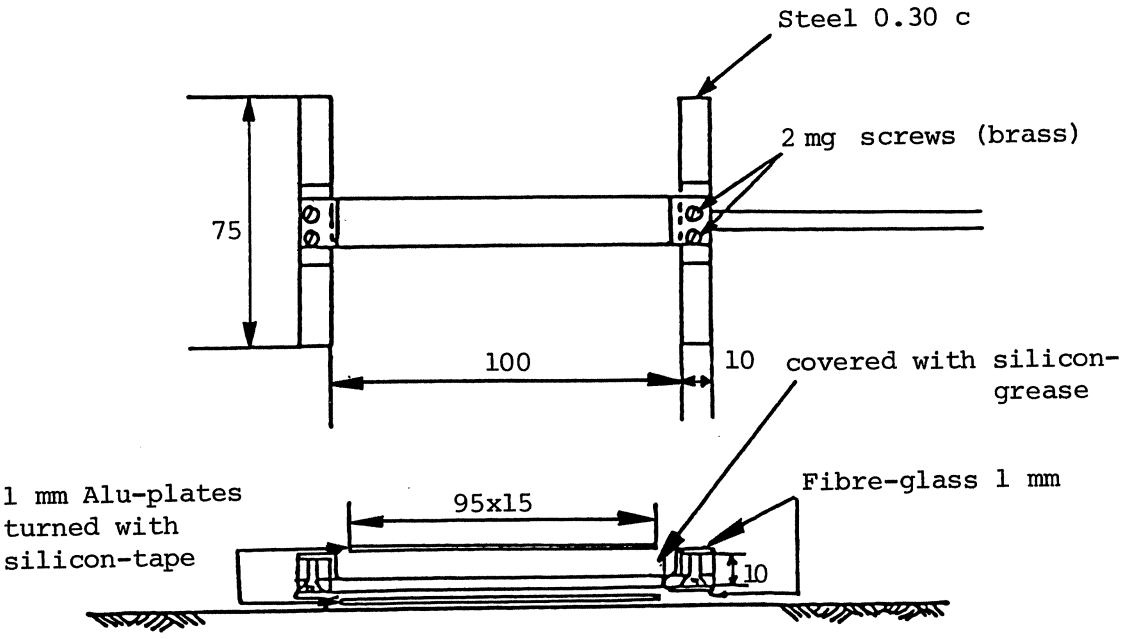
1. Team : No 7
   Equipe

2. Type of gauge : KYOWA KM-120-H2-11L 100-3
   Type de capteur : (Modulus: 2800 MPa, R = 120 Ω ± 1 %)

3. Manufacture : KYOWA - JAPAN
   Fabricant :

   Supplier : Instrutek 8700 DK
   Fournisseur :

4. Schematic drawing (plan and profiles)
   Schéma d'utilisation (plan et coupes)



5. Use (number, years, loss-rate) : 150, 1972, made
   Utilisation (nombre, années, pertes) :

6. Cost (US $) : 75 $ Loss-rate unknown, similar models have been
   Coût : made

7. Accuracy (theoretical) :
   Précision (théorique) :

8. Cables specification : Tygadure PTFE-wire 4 x 0.1 mm^2 (2 x 0.2 mm^2)
   Câbles : nr. CD 3463/1616

9. Comments :
   Commentaires :

Annex C.10

INQUIRY ON GAUGES
ENQUETE SUR LES CAPTEURS

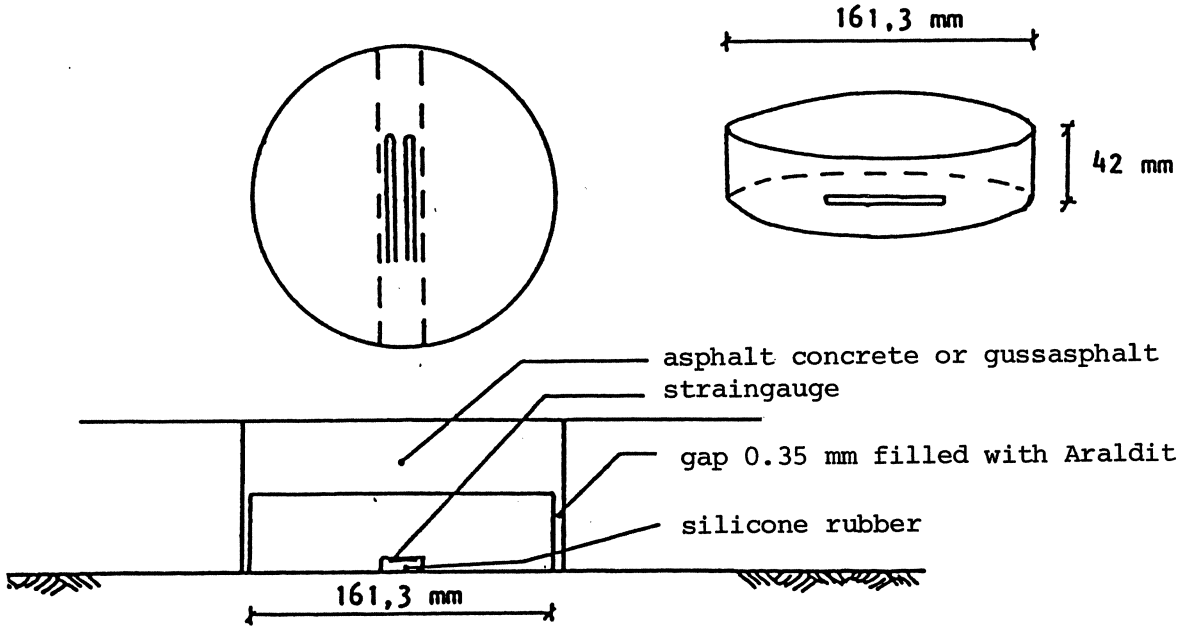
1. Team : No 8
   Equipe :

2. Type of gauge : in-cores-placement, FAE 2-300-35 PL (dual gauge)
   Type de capteur : active length 76 mm, R = 350 ohm

3. Manufacture : BLH-Electronics, USA
   Fabricant :

   Supplier : Suomen Bofors Oy, Helsinki
   Fournisseur :

4. Schematic drawing (plan and profiles)
   Schéma d'utilisation (plan et coupes)



5. Use (number, years, loss-rate) : 6 pieces since 1983, 0 % loss
   Utilisation (nombre, années, pertes):

6. Cost (US $) : 35 $
   Coût :

7. Accuracy (theoretical) :
   Précision (théorique) :

8. Cables specification : NOKIA KJMS 4 x 0.5 mm^2
   Câbles :

9. Comments :
   Commentaires :

Annex C.11

INQUIRY ON GAUGES
ENQUETE SUR LES CAPTEURS

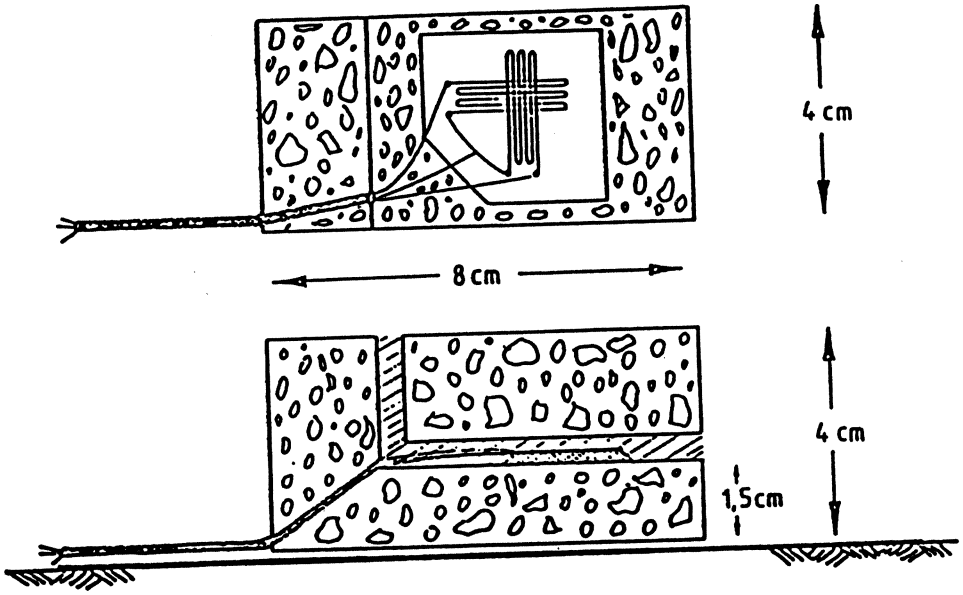
1. Team : No 9
   Equipe :

2. Type of gauge : Strain gauge within a block of asphalt concrete
   Type de capteur :

3. Manufacture : Strain gauge HBM Typ 20/600 XA21
   Fabricant :

   Supplier : Preparation of complete gauge: BAST
   Fournisseur :

4. Schematic drawing (plan and profiles)
   Schéma d'utilisation (plan et coupes)



5. Use (number, years, loss-rate) : ∿ 200, 20, ca. 25 %
   Utilisation (nombre, années, pertes) :

6. Cost (US $) : ∿ 10 $
   Coût :

7. Accuracy (theoretical) : unknown
   Précision (théorique) :

8. Cables specification : Teflon insulated cable, 2 wires + screen
   Câbles :

9. Comments : Principle of method adopted from SHELL
   Commentaires :

Annex D

List of the participants

Liste des Participants

COMMON PROGRAM OF MEASUREMENTS

PROGRAMME COMMUN DE MESURES

Nardò

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