

TECHNICAL METHODS FOR HIGHWAYS

Draft TMH3 **traffic axle**
load surveys
for pavement
design

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PREFACE

TECHNICAL METHODS FOR HIGHWAYS (TMH) is a series complementing the TECHNICAL RECOMMENDATIONS FOR HIGHWAYS (TRH) series. The TRHs are intended as guides for the practising engineer and leave room for engineering judgement to be used. The TMHs are more in the nature of manuals for engineers, prescribing methods to be used in various road design and construction procedures. It is hoped that these manuals will produce uniform results throughout the country.

This TMH was prepared by the Traffic Loading Subcommittee of the Highway Materials Committee, which is in turn a subcommittee of the Committee of State Road Authorities (CSRA).

To confirm the validity of these methods in practice, this TMH will be circulated in draft form for a period of trial before being submitted to the CSRA for final approval. During this period users are welcome to send suggestions for improvement to: The Division Director, Division of Roads and Transport Technology, PO Box 395, Pretoria, 0001. Eventually a revised manual, approved by the CSRA, will be issued as a full TMH in both official languages.

SYNOPSIS

Traffic axle load surveys are carried out in order to acquire data required for pavement design and for evaluation of pavement performance. Two weighing methods are available. Vehicles can be weighed while they are in motion – the dynamic method, or while they are stationary – the static method. The contribution of different characteristics of the vehicle to the measured axle load is discussed for a number of variables.

For the dynamic method, this publication describes the selection of weighing sites and three different types of weighing equipment in normal use. The calibration and accuracy of the equipment is discussed.

For the static method, the preparation of off-road weighing sites is discussed for different types of available equipment, and the calibration of the equipment is described. The static method of weighing yields more accurate measurements than the dynamic method.

SINOPSIS

Verkeersaslasopnames word gedoen ten einde data te bekom wat benodig word vir plaveiselontwerp en vir die evaluering van plaveiselgedrag. Twee weegmetodes is beskikbaar. Voertuie kan geweeg word terwyl hulle in beweging is – die dinamiese metode, of terwyl hulle stilstaan – die statiese metode. Die bydrae van verskillende eienskappe van die voertuig tot die gemete aslas word ten opsigte van 'n aantal veranderlikes bespreek.

Vir die dinamiese metode beskryf hierdie publikasie die keuse van weegterreine en drie verskillende tipes weegtoerusting wat normaalweg gebruik word. Die kalibrering en akkuraatheid van die toerusting word bespreek.

Vir die statiese metode word die voorbereiding van weegterreine wat langs die pad geleë is, ten opsigte van verskillende tipes beskikbare toerusting bespreek, en die kalibrering van die toerusting word beskryf. Die statiese weegmetode lewer meer akkurate metings as die dinamiese metode op.

KEYWORDS

Traffic axle loads, pavement design, weighbridge.

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1 INTRODUCTION AND SCOPE OF DOCUMENT

Road authorities require traffic axle load data as one of the basic inputs for planning and designing pavements and rehabilitation measures. Equipment is available for permanent or temporary weighing stations where vehicles may be weighed while stationary (static) or in motion (dynamic). The term "weighbridge" which is commonly used may be used interchangeably with "mass measuring bridge".

The input data required for pavement and rehabilitation design have changed markedly over the past twenty years. Initially, data were obtained by weighing vehicles statically. However, as the volume of traffic increased, it was possible to weigh only samples of the vehicle population. This necessitated the development of methods designed to estimate the total traffic load by using measurements of only a portion of all the vehicles. The procedures, known as Estimation Methods of Traffic, contained numerous shortcomings. These were overcome by measuring the weight of all passing vehicles without hindering their progress.

Although the procedures contained in this document may be applicable for other purposes, this document was prepared specifically for use in axle load surveys undertaken for pavement and rehabilitation design. Different aspects of dynamic weighing, including available equipment, measuring accuracy, calibration methods and guidelines for weighing, are covered in this document.

Vehicles can also be weighed statically, and descriptions of the methods used in different situations are given. These descriptions include the equipment available, calibration methods, measuring accuracy and techniques.

This document complements the recommendations provided in TRH 16¹ that deal with the application of data recorded in vehicle surveys undertaken for pavement design and performance investigations.

2 FACTORS AFFECTING VEHICLE WEIGHING

An understanding of the factors affecting vehicle weighing centres on the validity of the assumptions that:

- the load on the wheels of an axle remains constant at all times, ie remains the same as it was when the vehicle was originally loaded, and
- the load exerted on the road by any wheel of any vehicle, whether at rest or in motion, is constant and determined by the initial load distribution of the vehicle.

These assumptions disregard the fact that the load concentration on a wheel or an axle changes continuously when the vehicle is in motion. Such changes result from a number of factors including the design, construction and mechanical condition of the vehicle, the gradient and surface roughness of the road and the way in which the vehicle is driven (eg acceleration, braking, cornering). Other factors such as the weather should also be considered, eg under dry conditions leaf springs flex less easily than under wet or moist conditions, since moisture acts as a lubricant between the leaves. Wind may also cause an increase in load on the sheltered side of a vehicle. Therefore the force imposed on the road by an axle or a wheel, as a dynamic load, depends on the transient variations of these factors with regard to time and position.

Under specific circumstances, an operator measuring vehicle weight may consider weighing individual axles and summing the weights to obtain the gross vehicle weight, as an alternative to using a vehicle scale. Since a number of errors may be introduced by such an approach, the operator should consider the accuracy required before adopting such a procedure.

2.1 VEHICLE LOAD DISTRIBUTION

Basic misconceptions concerning vehicle weighing are derived from the fact that the load concentration or distribution is not constant. A wheelbarrow, the simplest of all vehicles, may be used to illustrate this point. As the handles of the barrow are either raised or lowered, the centre of mass moves in relation to the wheel and thus the load on the wheel changes, both vertically and horizontally.

The mass on two adjacent wheels of a truck is the same only if the tyres and tyre pressures are similar. It has been found that if the pressure in one of the two adjacent wheels of a dual-wheeled axle is decreased from 400 kPa to 200 kPa, then it is possible that 25 % of the load is transferred to the 400 kPa wheel.

For similar reasons, it is important that vehicles should be weighed on an as level a site as possible, and that every effort should be made to have all the

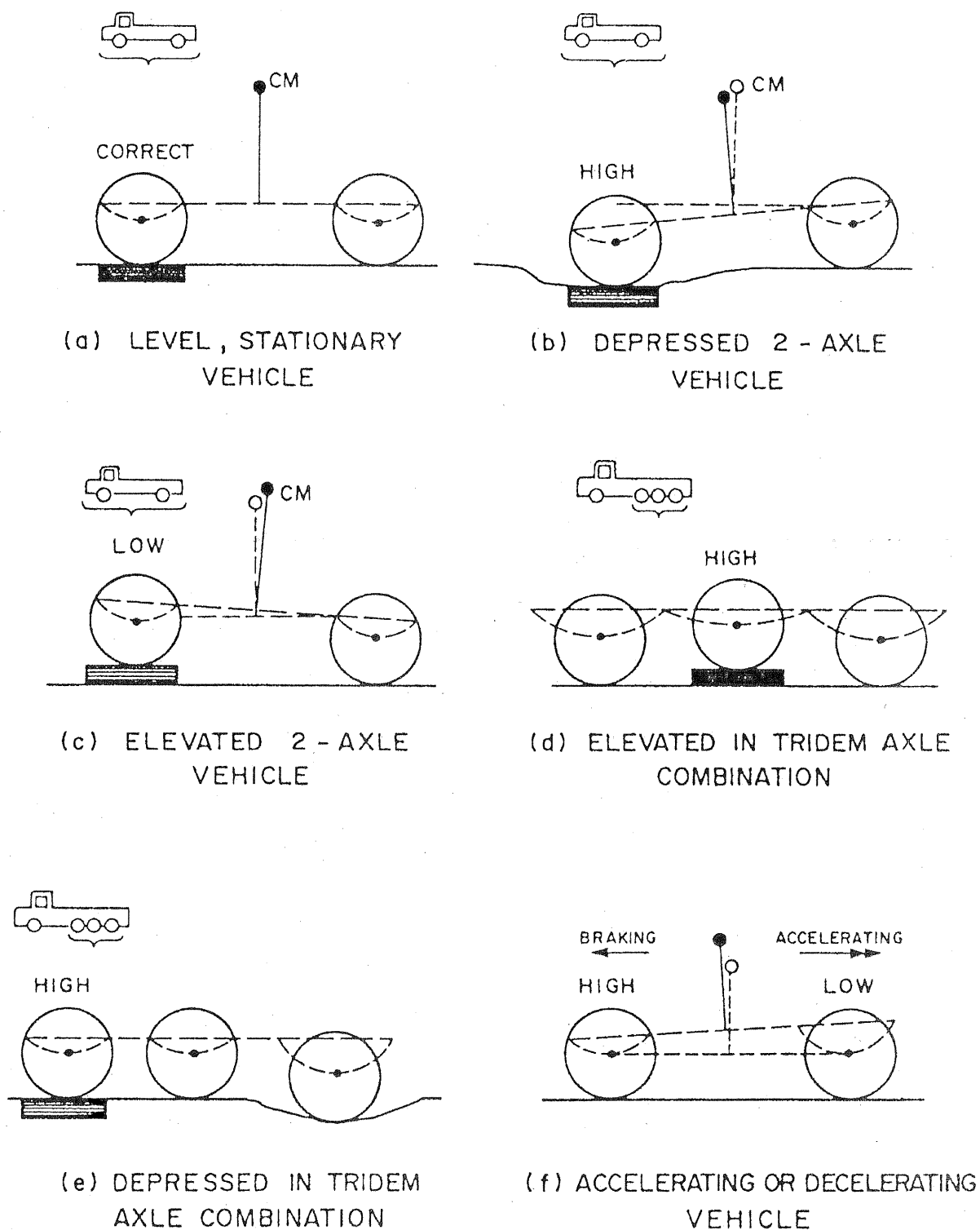


FIGURE 1
ILLUSTRATION OF CORRECT AND FAULTY VEHICLE AND AXLE
PLACEMENT WHEN WEIGHING

wheels of a vehicle at rest on a common plane. For example, if the weighing platform raises the level of the wheels to be weighed above the plane of the remaining wheels of a vehicle with two axles, a decrease in measured load may result. Similarly if the level of the weighed wheel or axle is lowered there may be an increase in measured load. This is illustrated in Figures 1(a) to (c), while the situation for multiple axles is shown in Figures 1(d) and (e). When a truck or trailer has more than two axles, the "inner" axles could either be too heavy or too light because one or more axles carry the other, depending on the suspension system. This is particularly true of tandem axle assemblies.

With regard to the above, the degree of error introduced will depend on:

- the degree of slope or plane of the weighed axle;
- the wheel base, ie the spacing between the wheels, and
- the height of the load above the centre of gravity of the axles.

The error will be smaller for a long wheel base than for a short one, as well as for a low rather than a high centre of gravity. In most cases the actual degree of error introduced will depend on the type of vehicle suspension system.

2.2 VARIATIONS IN THE LOAD DISTRIBUTION OWING TO THE MOTION AND BRAKING OF A VEHICLE DURING STATIC AND REDUCED SPEED WEIGHINGS

Acceleration and deceleration of a vehicle are affected by horizontal forces, but these in turn induce vertical loads in the suspension of the vehicle through a coupling effect. Braking causes an increase of the load on the front axle and a decrease on the rear axle. The converse applies for acceleration. Only some of this load shift may be caused by braking, and not all of it will be relieved when the brakes are released (Figure 1(f)).

This may be illustrated by weighing the tandem-axle of a heavy vehicle. If the brakes are applied suddenly to make the wheels stop on the centre of the scale, some of the rear axle load is transferred to the front axle of the tandem. On releasing the brakes, some of the load may be shifted to the rear axle, depending on the stiffness of the shackles and pivot points. However, the front axle will still carry more than its fair share of the load, and will indicate a high mass. When the vehicle is driven forward, a load redistribution takes place and the load increases slightly on the rear axle (smooth driving will minimize this effect, while a jerky forward movement will aggravate it).

For these reasons every effort must be made to ensure that the vehicle moves slowly but steadily whilst on the weighing site, and that the motion is not jerky. It is also clear that the brakes must be fully released when the measurement is taken. Correct lubrication of the suspension (over which the surveyor has no control), will ensure that residual movements or stresses are minimized.

An error of up to 10 % may be measured with heavy braking if the brakes are not released when the vehicle has stopped on the scale. This is reduced to less than 1 % if the brakes are released before the measurement is taken.

2.3 REPEATABILITY OF A MEASUREMENT

Differences may be expected between successive static measurements of an axle load. These are caused by a number of factors, for example a shift of cargo or the centre of the vehicle's mass, a change in the position of the axles in their bearings or the linkage of an articulated vehicle, and a change in the vehicle's alignment to the scale and the smoothness of the approach.

By way of demonstration, repeated static test weighings (10 repetitions) of a bus, registered standard deviations of 0,73 % and 1,05 % for the two left rear wheels and two right rear wheels respectively². This was due to the mechanical effects of springs, shackles, and so on, and a change in load distribution through friction. Wind blowing on the bus could also have played a role.

Consequently, static measurements of heavy vehicles are frequently taken in both the forward and the reverse direction, the results being averaged to ensure that the above influences are minimized.

2.4 MEASURING ACCURACY

From the above discussion it can be seen that weighing individual axle loads of a vehicle and adding the results, and assuming that the sum represents the true weight of the whole, presupposes that the load on each axle remains constant during the entire weighing procedure. This latter condition pertains only under certain favourable but uncommon circumstances.

3 DYNAMIC VEHICLE WEIGHING

At sites such as multi-lane highways, where the terrain and traffic flow do not allow for the static weighing of all vehicles or for a representative sample to be obtained with one of the traffic estimation methods, the in-motion or dynamic method of vehicle weighing is recommended.

When data are required for road design purposes, the traffic should be measured for at least a week at a given site. Two major types of dynamic weighing equipment are available:

- (a) Permanent or semi-permanent units for normal and reduced road speeds.
- (b) Portable units for normal and reduced road speeds.

3.1 WEIGHING ACCURACY

Dynamic weighing is not as accurate as static weighing because of influences of unevenness of the road surface leading up to the weighing site, resulting in a dynamic variation of axle weight. It has been found that errors of up to 10 % and less than 4 % may be expected for traffic travelling at normal (up to the speed limit) and reduced (up to 20 km/h) speeds respectively.

The main advantage of portable sensors is that they are easily installed, and although the measuring error is greater than with permanent equipment, evaluations have shown that this may be reduced to less than 5 %³. For pavement design purposes, errors of below 10 % are generally regarded as acceptable.

3.2 SITE SELECTION

The section of road to be surveyed should be known before the point can be determined at which the system is to be installed.

The following technique, which is also outlined in Figure 2, is normally used to select a site:

- (a) Measure the riding quality of the portion of road under consideration by means of a Portland Cement Association (PCA) roadmeter or Linear Displacement Integrator (LDI) (Figure 3). Candidate sites are those where a 100 m section has a PSI (present serviceability index) greater than 2,8. On roads with a riding quality poorer than a PSI of 2,8, random high or low measurements (outside the accuracy range given above) could occur for different vehicle configurations.

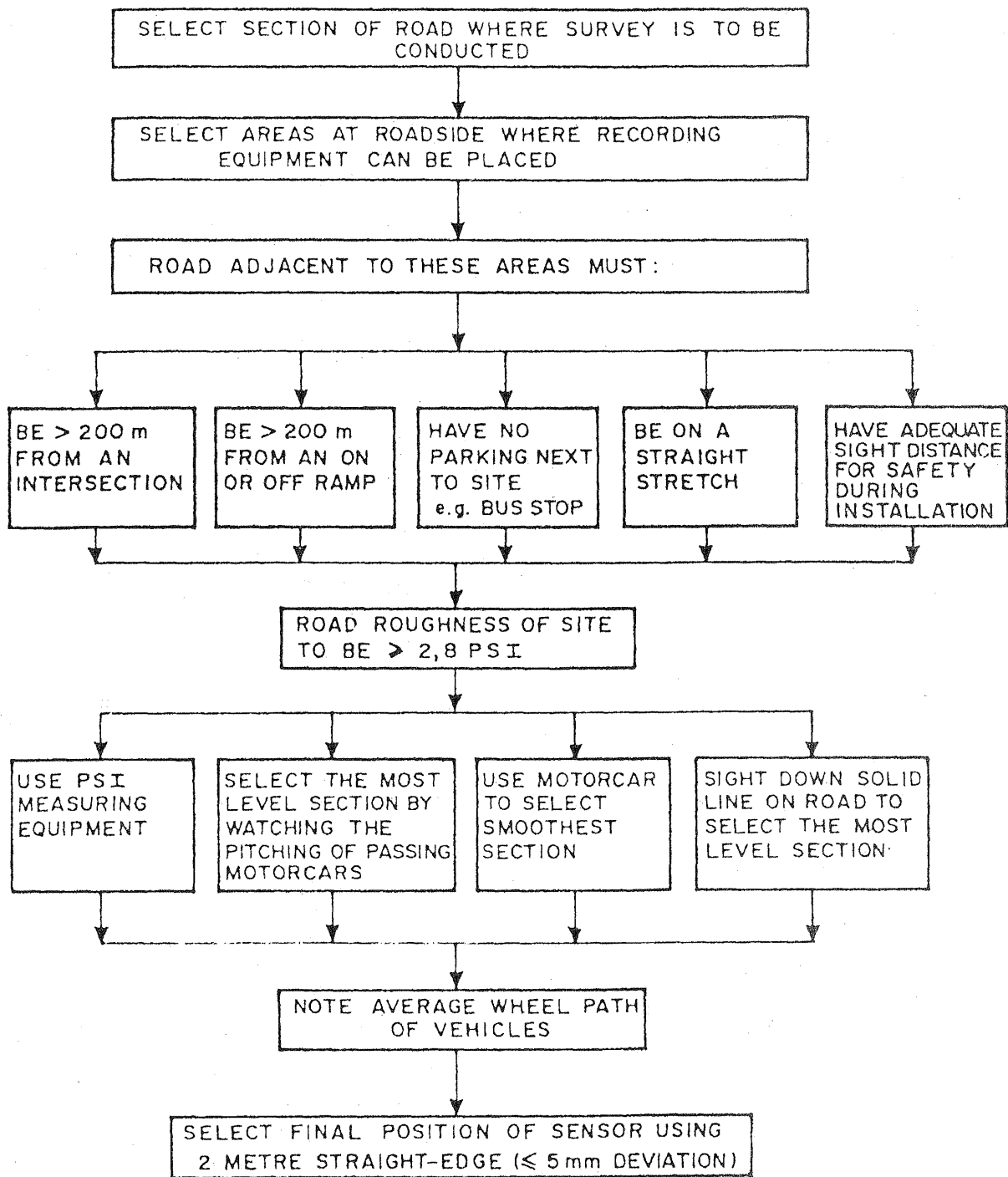


FIGURE 2
SELECTION OF DYNAMIC WEIGHING SITE

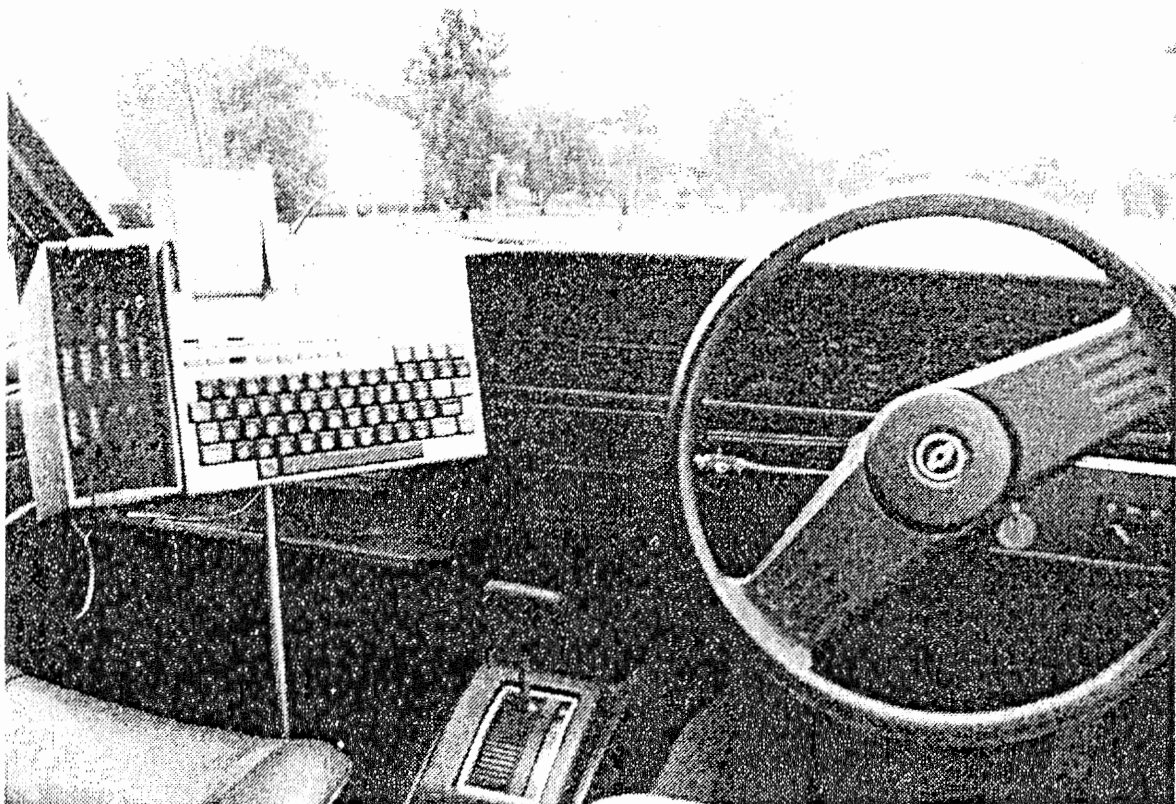
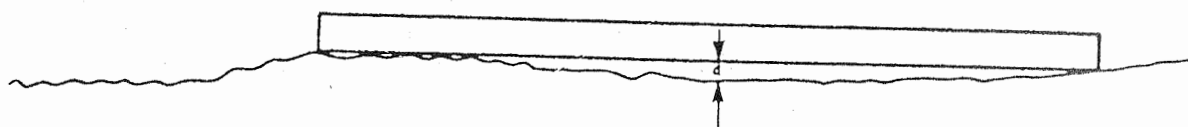


FIGURE 3

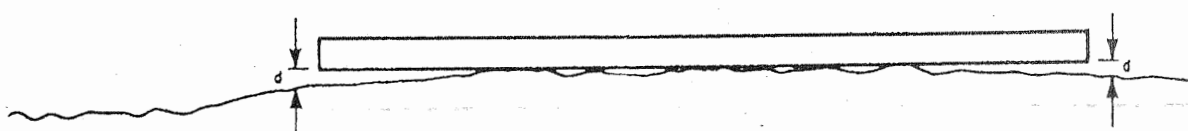
VEHICLE FITTED WITH PCA ROADMETER

- (b) Extreme care should be exercised in selecting a site for a semi-permanent station, when equipment is to be reinstalled at regular intervals to measure long-term changes in traffic distributions.
- (c) Prospective sites should be compared by using a 2 m straight edge, and the site with the most even transverse profile should be selected. If the transverse unevenness over 2 m, measured as shown in Figure 4, exceeds 5 mm, the site is unacceptable.
- (d) The above points apply to all lanes on a multi-lane highway, where a weight sensor is to be placed in each traffic lane as illustrated in Figure 5. It is advisable to select a site where the lanes and shoulder are clearly demarcated and a minimum of weaving takes place.
- (e) The surface and shoulder at the site should be free of loose stones as these could be thrown onto and crushed into the sensor by passing traffic.
- (f) The site should not constitute a hazard to the normal traffic flow.
- (g) Care should be taken during the survey that the normal flow of traffic is not affected by parked vehicles.

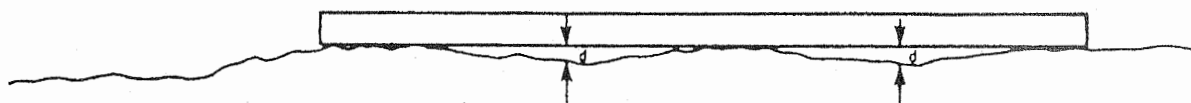
CASE 1 : CONCAVE SURFACE



CASE 2: CONVEX SURFACE



CASE 3: MULTIPLE DEPRESSION OF SURFACE



d = DEGREE OF NONUNIFORMITY - MAXIMUM OF
5mm IS ALLOWED

FIGURE 4
MEASUREMENT OF TRANSVERSE UNEVENNESS WITH 2 METER
STRAIGHT-EDGE

- (h) The site should be an adequate distance from a corner or bend in the road so as not to alarm the driver.

In many cases riding quality equipment may not be available, or the location of a site may have to be verified. Under such circumstances, the position of the sensor site can be selected while riding in a motor car, and by choosing the 100 m long section that gives the smoothest ride. This position can be

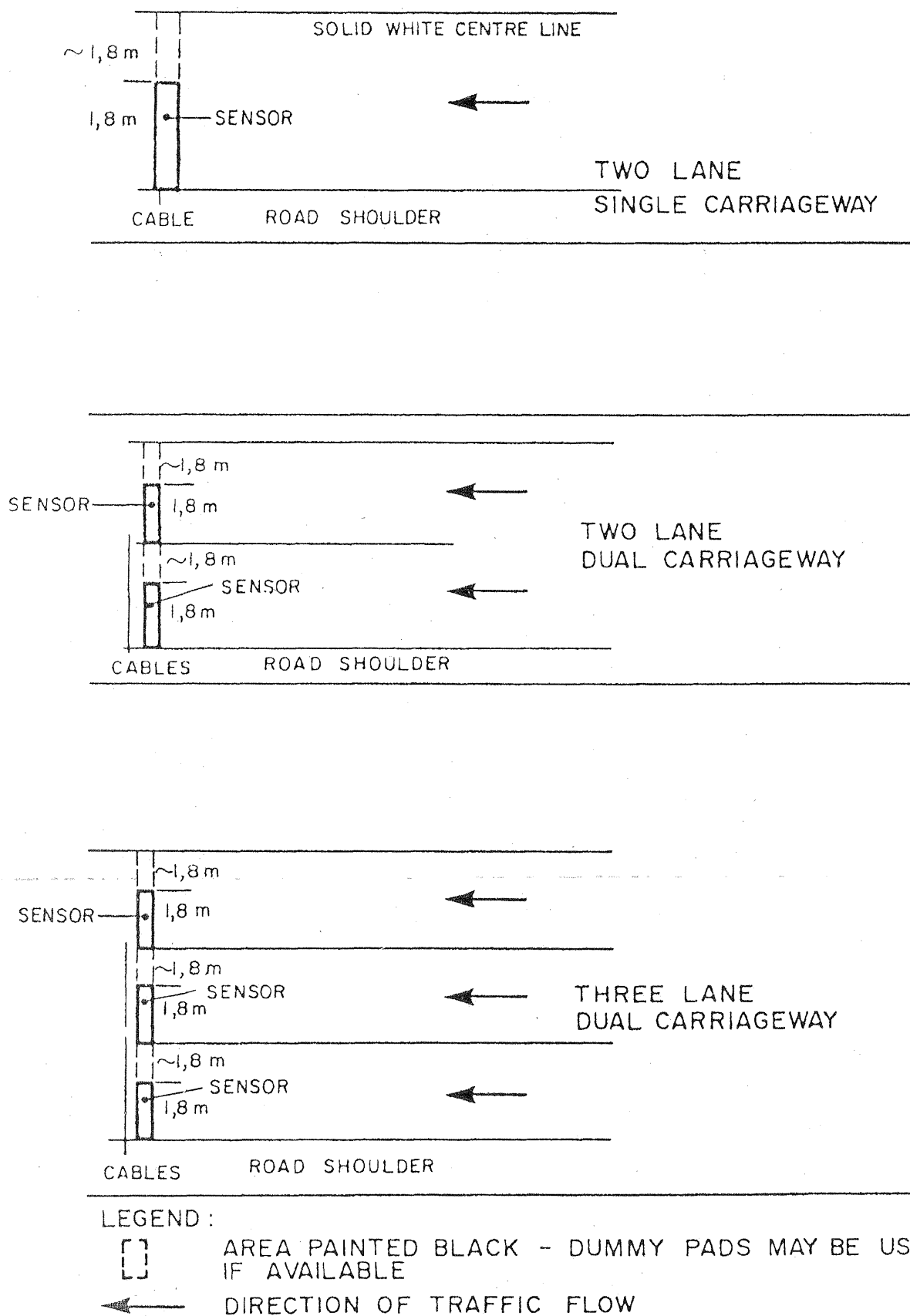


FIGURE 5
SENSOR LAYING PATTERNS

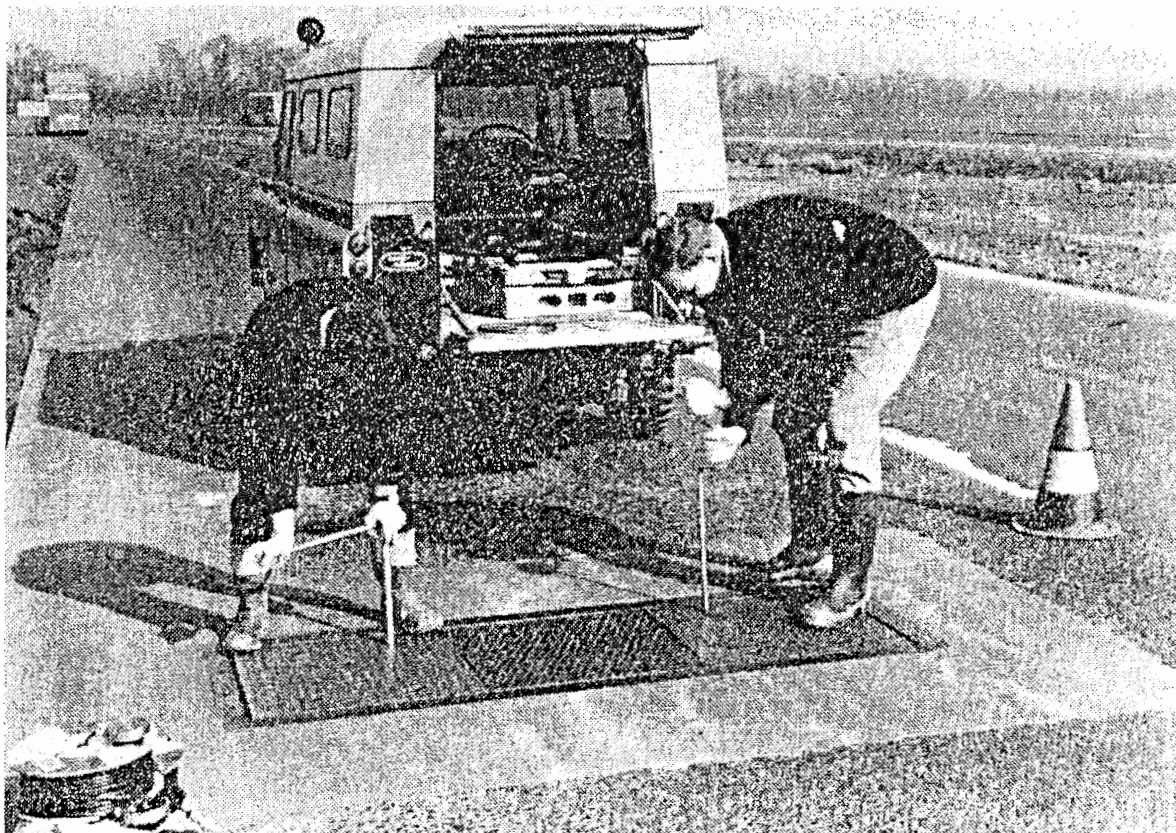


FIGURE 6
PERMANENTLY INSTALLED OR TRANSPORTABLE AXLE SCALE

verified by standing at the roadside and watching the pitching of passing vehicles. Another useful technique is to sight along a solid line which has been painted on the road to demarcate a lane. When doing this, any undulations can be clearly seen.

Once the site has been selected, the correct lateral positioning of the weight sensor has to be determined. This is done by observing where most of the traffic travels within each lane. The weight sensor is then placed such that most of the traffic is monitored.

3.3 AVAILABLE EQUIPMENT

A wide range of equipment is available⁴. This may be grouped into three classes, namely permanent weighbridges, transportable scales and portable units. The equipment varies significantly with regard to design, installation and operation. The majority of permanent weighbridges are installed within two man-days per traffic lane.

A transportable scale that requires site preparation is installed in a traffic lane by a team of two within a day, while a portable unit is installed in a traffic lane within thirty minutes by two operators.

The electronics associated with this range of equipment also varies. At one end of the range, torch cell batteries power the classifier that groups axle weights into given categories. At the other end of the range, traffic data are recorded and stored in the equipment's memory on site. This data can be preprocessed on site and transferred to a cassette tape on demand, or to the mainframe computer for further processing via an acoustic coupler.

3.3.1 Permanently installed or transportable axle scales for weighing at normal speeds

These axle scales are most suitable for monitoring traffic trends in high density areas having an established road network. The scales (Figure 6) are mounted in a prepared foundation, flush with the road's surface. They are mechanically robust but are reported to be sensitive to moisture due to the high impedance of the load cells used.

The main disadvantage of this type of weighing system is the site preparation needed to install the load platform. A Portland cement concrete foundation is generally desired, and at least a day is needed for installation.

The monitoring equipment is normally mains powered. It does not have a vehicle speed measuring facility, and the equipment can only accumulate axle data on a time scale.

3.3.2 Permanently installed or transportable axle scales for weighing at reduced speeds

These scales are similar to those described in the previous section, except that their response requires that measurements be taken with vehicles moving at 10 – 20 km/h. One available model (Figure 7) is normally used on a service road or lay-bye where vehicles travel slowly along a marked route. The unit is installed in a prepared pit (Figure 8). The weighbridges can be replaced with dummy cells when the site is not in use, so that the same sensors can be used to service a number of sites.

This equipment is normally used to accumulate axle data, and to record a sample of traffic in cases where the flow prohibits the measurement of all vehicles.

3.3.3 Portable axle scale or axle weight sensor that requires no prior site preparation for weighing at normal speeds

This scale is of low profile to enable it to be secured to the surface of the road using a 'peel and stick' adhesive. Installation of the two loop detectors, axle weight sensor and axle detector (Figure 9) can be completed within an hour by two operators. The object of the complex sensor system used, is to enable the battery powered equipment to monitor the following vehicle and traffic parameters:

- Axle weight
- Axle spacing
- Vehicle length
- Tyre contact length
- Vehicle speed
- Separation between vehicles.

These data can be transferred to the main computer via a telephone link or stored on removable memory units for transfer to the computer, where the data are processed.

A simpler data collection unit which is connected only to weight sensors, is also available. With this, axle weight data is collected over known time intervals.

3.4 CALIBRATION OF AXLE WEIGHING EQUIPMENT

It is important, with the dynamic weighing of axles, to check the equipment's performance every time it is installed, or at least once a week when operating permanently installed equipment.

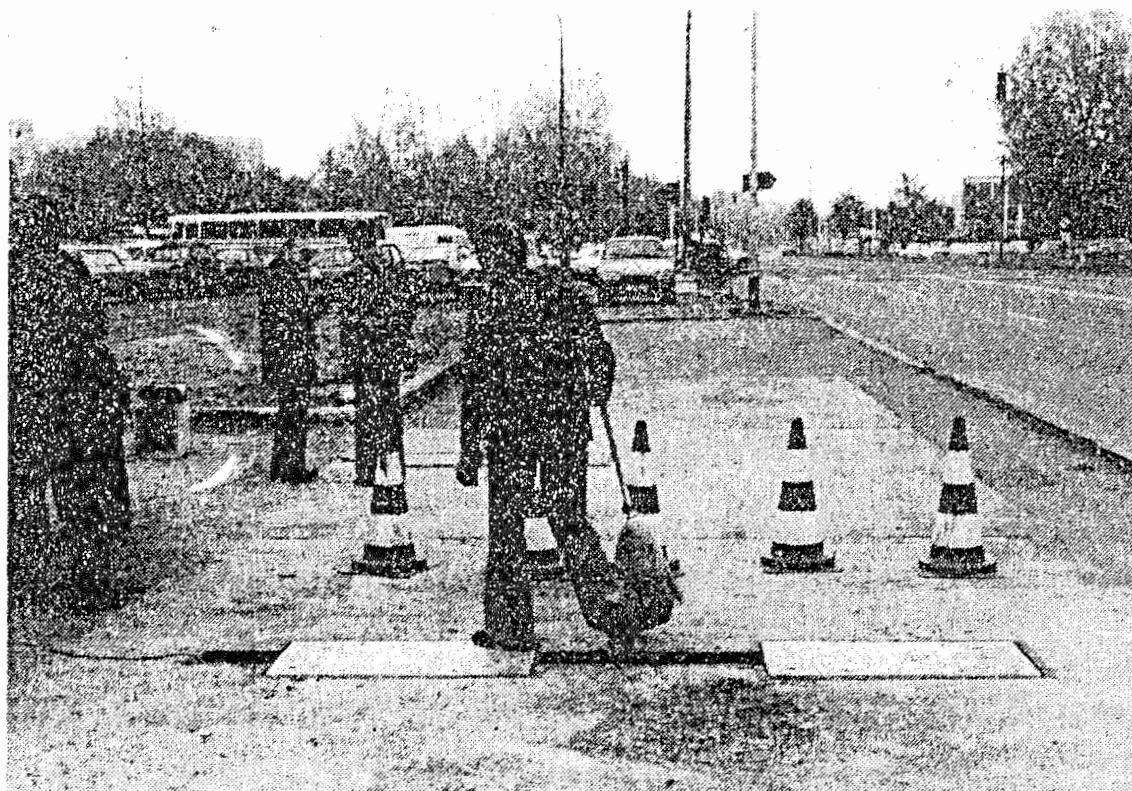


FIGURE 7

*LOW-SPEED PERMANENTLY INSTALLED OR TRANSPORTABLE
AXLE SCALE*

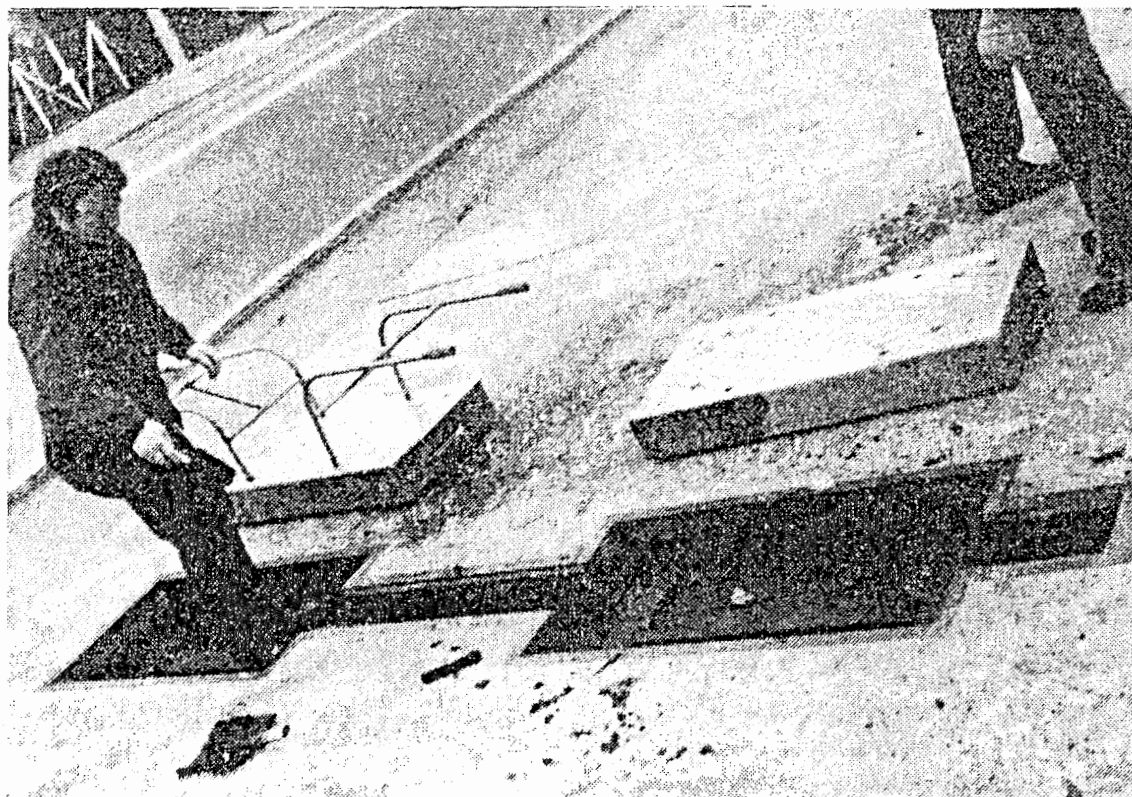


FIGURE 8

FOUNDATION FOR AXLE SCALE LOAD-CELLS



FIGURE 9
*PORTABLE AXLE WEIGHT SENSOR AND VEHICLE
DETECTORS*

3.4.1 Permanently installed and transportable axle scales

The calibration of these scales, which are installed with their upper surface flush with that of the road, is similar to that of static scales. Manufacturers are able to calibrate their units at facilities at the factory. However, the user is best able to calibrate the unit with assized weights when it is installed on site. These weights are positioned with a crane that is fitted to the truck which is

used for conveying them to the site. The weights, which should register for at least four points in the range 4 – 16 tons, must be placed on the weighing area so as to avoid uneven loading of the scale. If it is inconvenient to transport the weights to the site, two trucks having known axle loads that cover the legal range will provide a reasonable indication of the equipment's accuracy. The trucks may be weighed statically and dynamically on the scales to assess the influence of the approach to the site.

3.4.2 Portable axle weighers

Portable scales are not designed to be operated at a particular site for any length of time, as the method of installing the weight sensor necessitates that the adhesive plates used be inspected every week. The scales are installed on the road surface and are not recessed in a pit. This introduces an additional weight component known as the impact factor, which is measured and compensated for by the equipment.

The manufacturer, who has the necessary equipment at the factory, normally calibrates the weight sensor. To test the equipment's performance after installation, a heavy vehicle of known axle mass may be driven over the scale at a normal road speed. The recordings may then be compared with the known data to confirm that all is in order before the survey is initiated.

In certain cases it may be necessary to perform a field calibration. One method for carrying this out is to use the traffic stream. The equipment should be installed⁵ near a static weighbridge or axle mass measuring system. The sensor's output can then be compared with corresponding statically measured axle loads of a random sample of passing traffic. Experience has shown that a random sample, covering the axle load range, provides the best results, since selected vehicles may produce biased readings. A minimum of 100 axles is regarded as an adequate sample. To check the effect of the unevenness of the approach, the results of this experiment may be tested by moving the dynamic weighbridge 100 m down the road, and repeating the exercise. The recordings of individual vehicles will be different, owing to a change in the phase of oscillation of the vehicles as they cross the site. Similar tests may be done for vehicle speed, axle spacing, vehicle length and headway, if the equipment is designed to measure these parameters. When a discrepancy in the equipment's calibration is found, this may be corrected by consulting the handbook or by contacting the manufacturer concerned.

4 STATIC VEHICLE WEIGHING

At sites where the terrain and traffic flow allow for the static measurement of all or a sample of the passing vehicles, weighing is usually carried out during daytime over a period of two to three days; for example Tuesday, Wednesday and Friday. This exercise is combined with a visual survey to obtain an estimate of the total traffic at the site.

A method of converting vehicle weighing and visual data to total standard axles (E80s) is given in TRH16¹. These results are then used in pavement design as detailed in TRH4⁶.

4.1 WEIGHING ACCURACY

When vehicles are measured statically, the time taken to weigh each unit dictates that on heavily trafficked routes only a sample of the total traffic can be measured. As this sample constitutes only a fraction of the total, more accurate measurements are required than when all the passing vehicles are measured dynamically. Static weighing is normally accurate to within 1 %⁷.

4.2 SITE SELECTION

Sites for static weighing should be situated:

- on a straight section of road;
- on a reasonably smooth stretch of road with a gradient less than 2 % and normal crossfall or camber, and
- at least 200 m beyond an intersection, turn or bend in the road, to ensure safety at the site.

Sites for static weighing vary according to the requirements. Permanently installed weighing facilities vary from a simple roadside installation (Figure 10), to a more complex layout having its own access, resting area, fuel and motor repair depot, restaurant and toilet facilities (Figure 11). Portable axle scales are used where possible on roads with shoulders that are wide enough to accommodate a heavy vehicle without interfering with the normal flow of traffic (Figure 12). In some cases, warning signs must be erected⁸ to ensure the safety of the weighing team. Where there is no shoulder and where the flow of traffic permits, one traffic lane may be closed for the duration of the weighing exercise (Figure 13). This procedure has proved successful with adequate traffic control (signposting and traffic officer). During these surveys, portable scales such as those illustrated in Figure 14 are used. No site preparation is necessary, as wooden boards of the same thickness as the scales are used to raise all the wheels to the same plane



FIGURE 10.
PERMANENTLY INSTALLED ROADSIDE AXLE SCALE

(Figure 15). It is most important for the safety of the weighing team that oncoming vehicles have adequate warning, so that they are able to slow down sufficiently before reaching the site.

4.3 AVAILABLE EQUIPMENT

Mass meters fall into two general categories which contain electronically, hydraulically or mechanically operated systems or a combination of these. These two categories are:

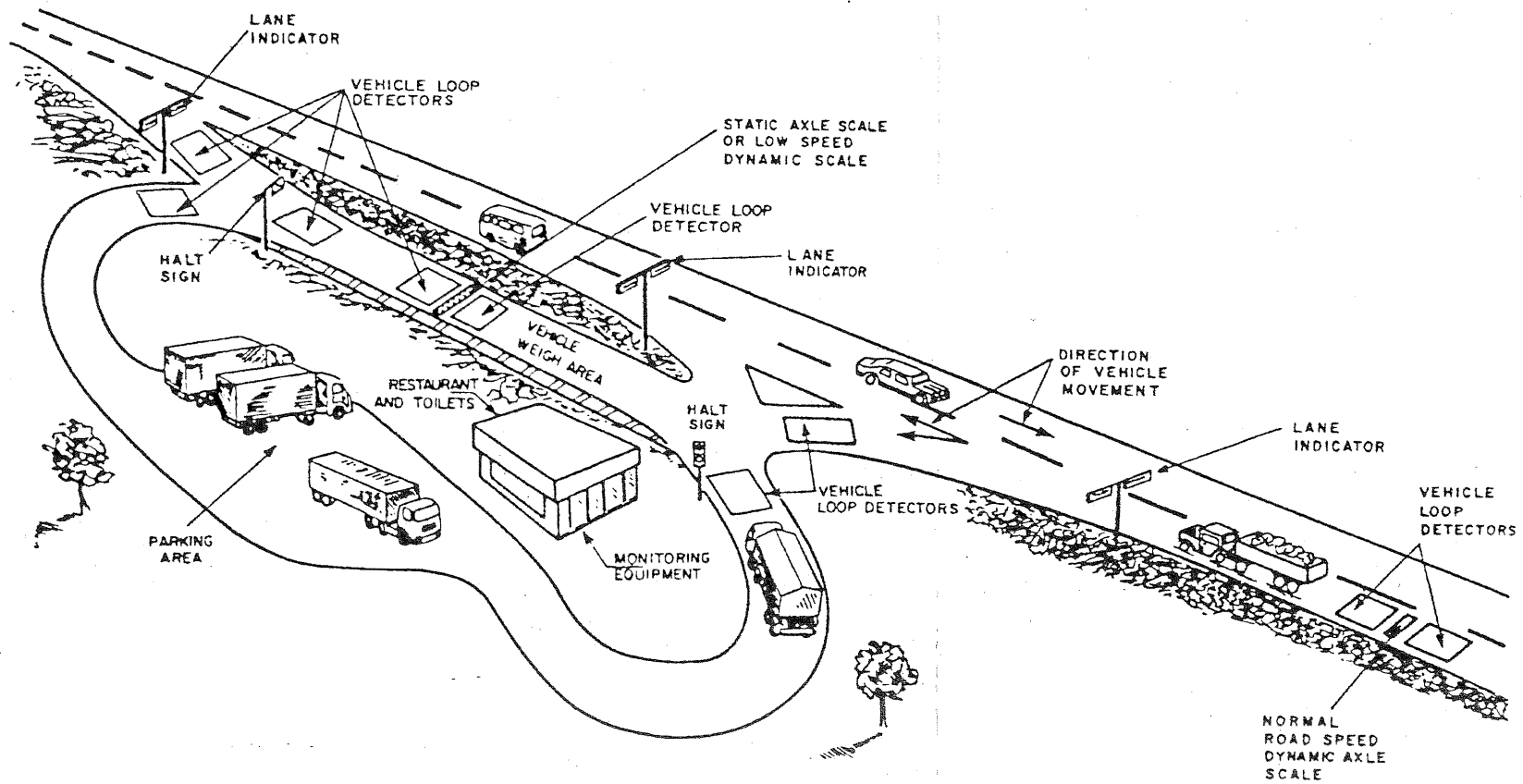
- (a) Axle measuring scales and individual wheel weighers.
- (b) Weighbridges for vehicles.

Each category has a specific area of application which should be considered when selecting a system.

4.3.1 Axle scale and individual wheel weigher

In this category, the beam to support the axle is of necessity a unit, and is not easily moved. Together with its foundation it may be regarded as a permanent installation. The load measuring units are either built into this

FIGURE II
FULL FACILITY PERMANENT WEIGH-STATION



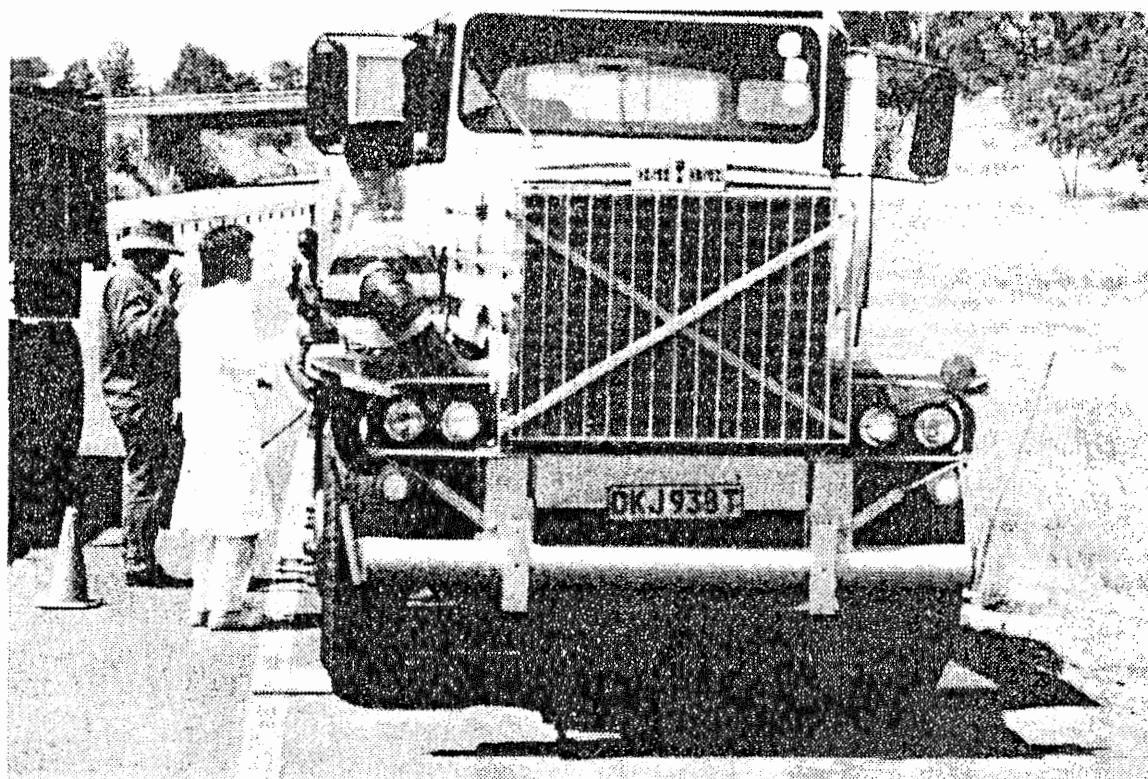


FIGURE 12

TEMPORARY WEIGH - SITE AT ROADSIDE

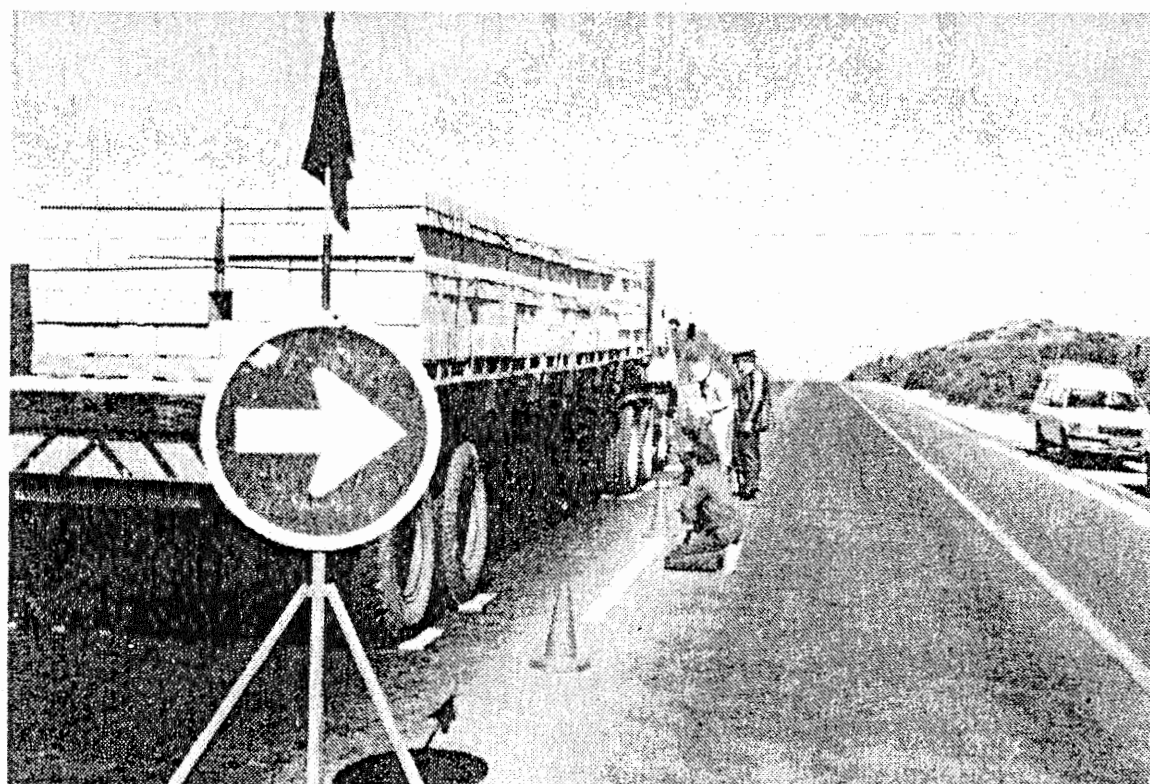


FIGURE 13

WEIGHING OF VEHICLES IN ROADWAY

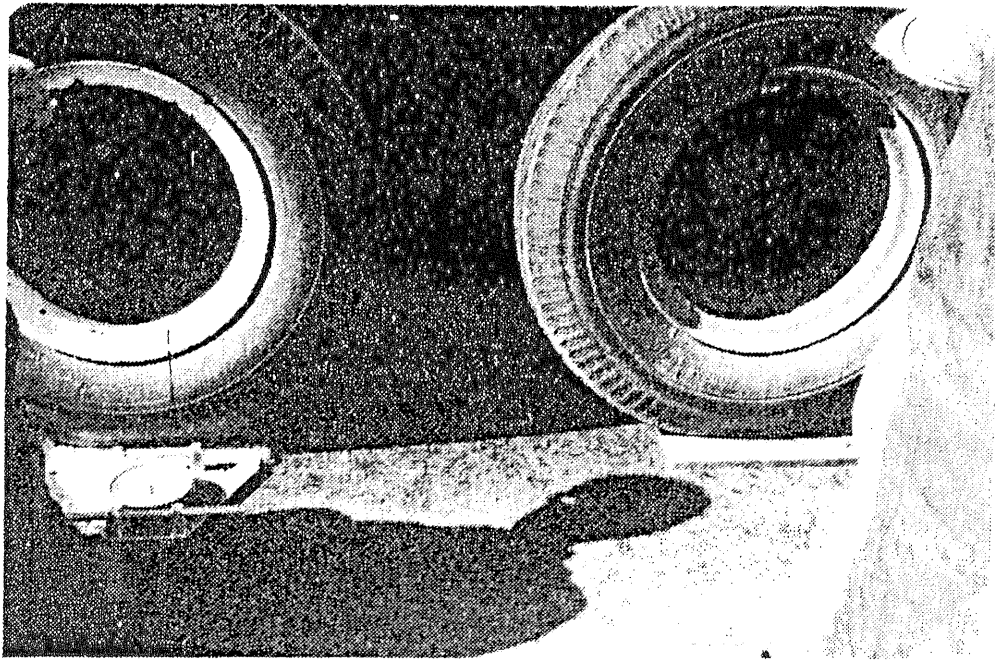


FIGURE 14
PORTABLE SCALES USED ON UNPREPARED SITES

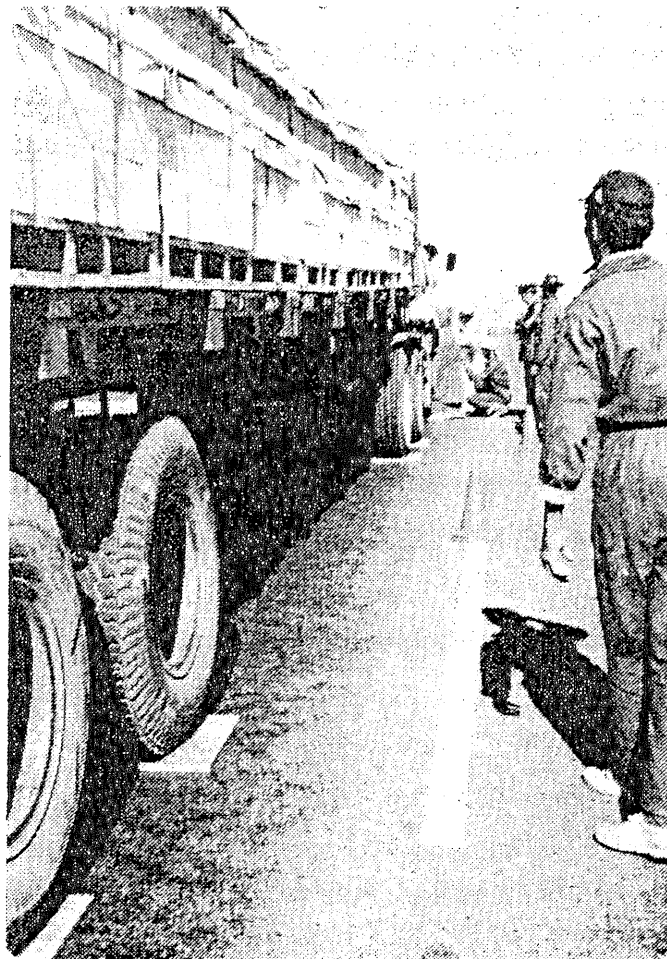


FIGURE 15
*RAISING OF ALL WHEELS TO THE SAME PLANE
ABOVE THE ROAD*

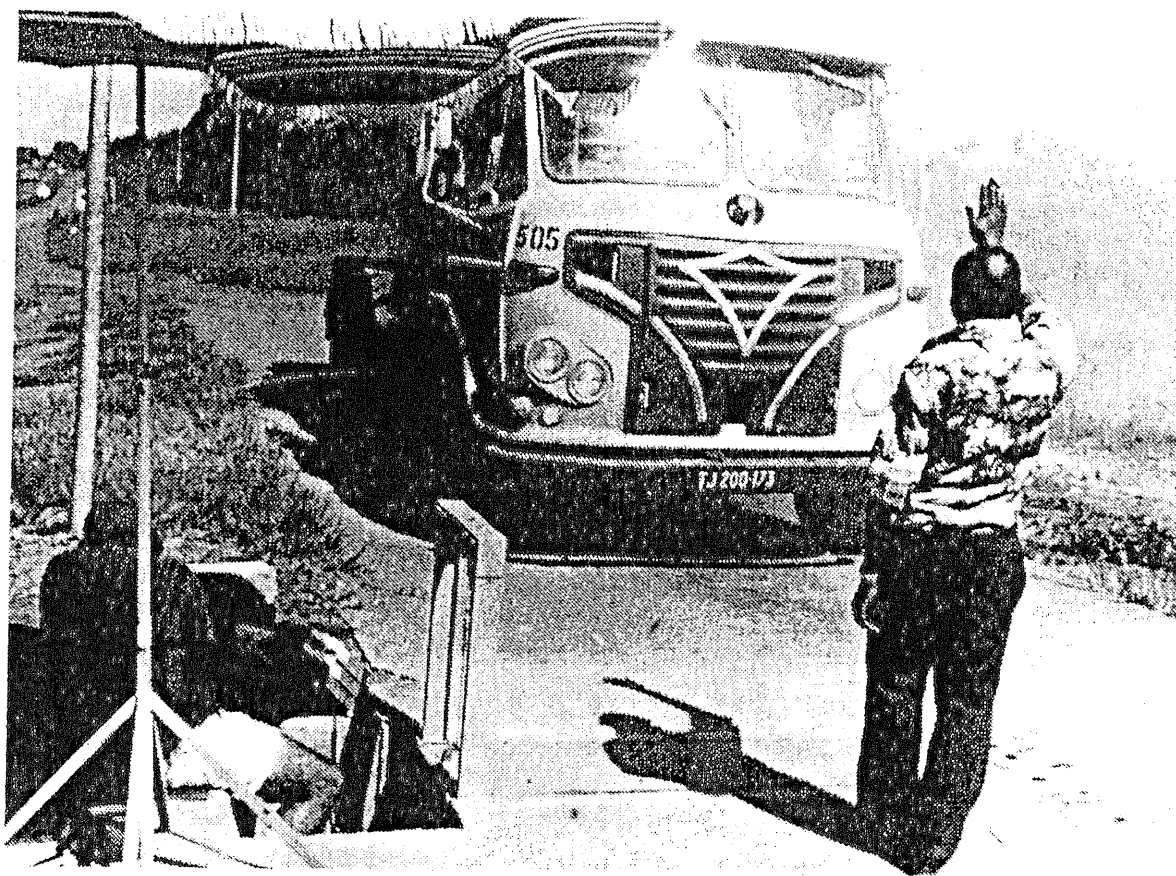


FIGURE 16

PORTABLE WHEEL WEIGHERS USED WITH A BEAM TO WEIGH AXLES



FIGURE 17

PERMANENT WEIGHBRIDGE TO ACCOMMODATE A FULL VEHICLE

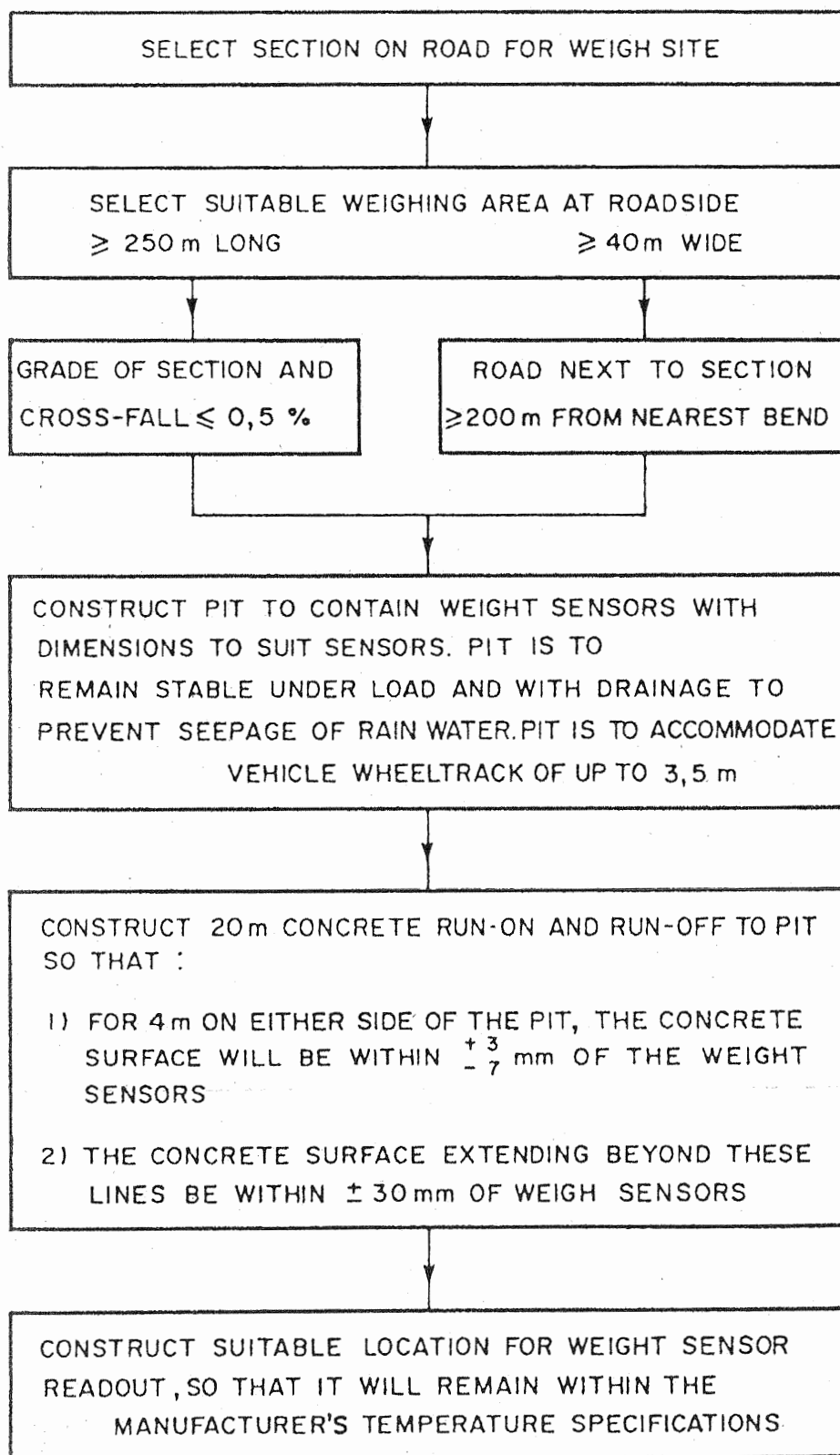


FIGURE 18

*CONSTRUCTION OF OFF-ROAD VEHICLE WEIGH SITE
FOR STATIC MEASURING*

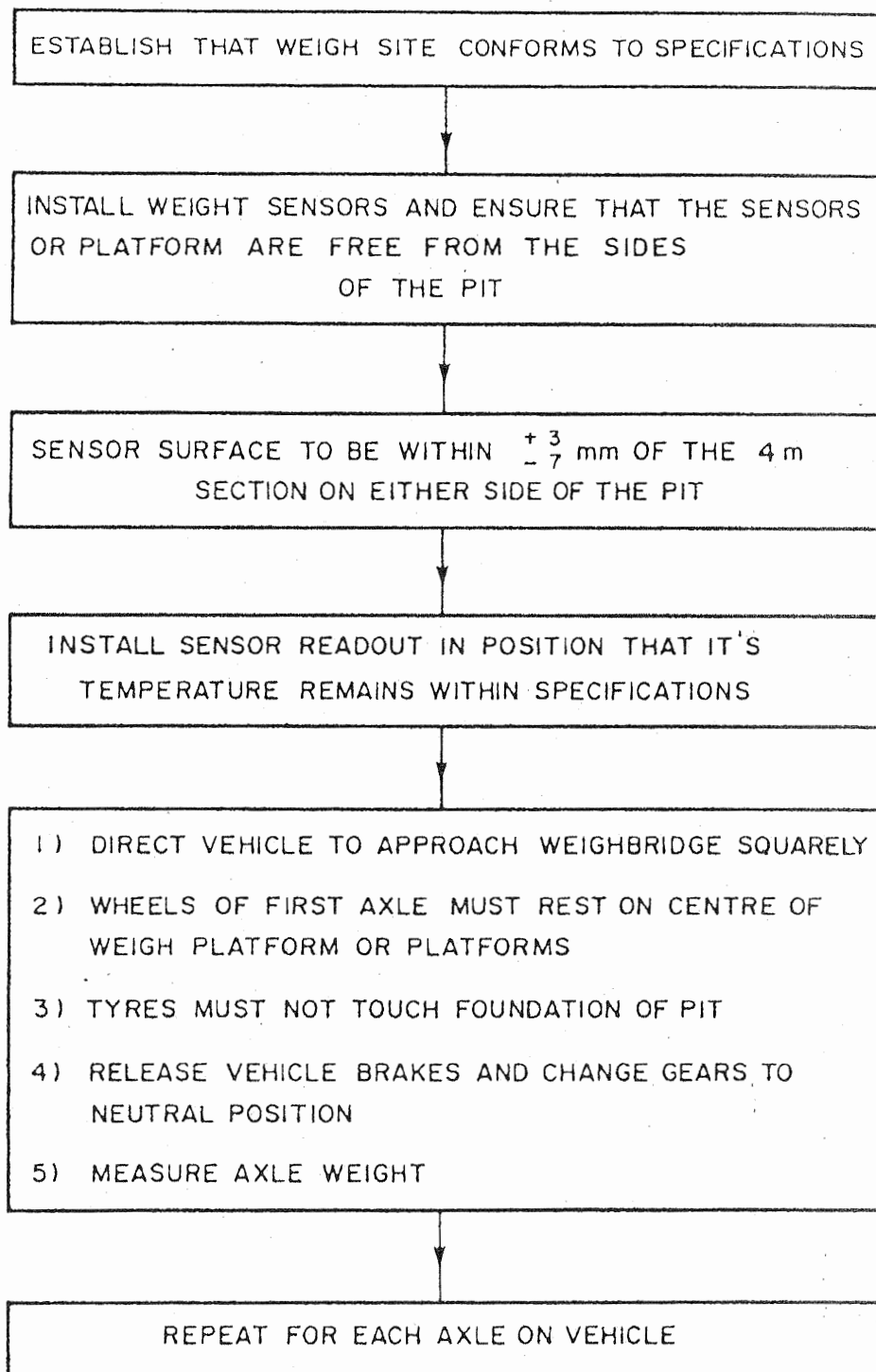


FIGURE 19

*PROCEDURE FOR WEIGHING VEHICLES STATICALLY
ON PREPARED OFF-ROAD SITE*

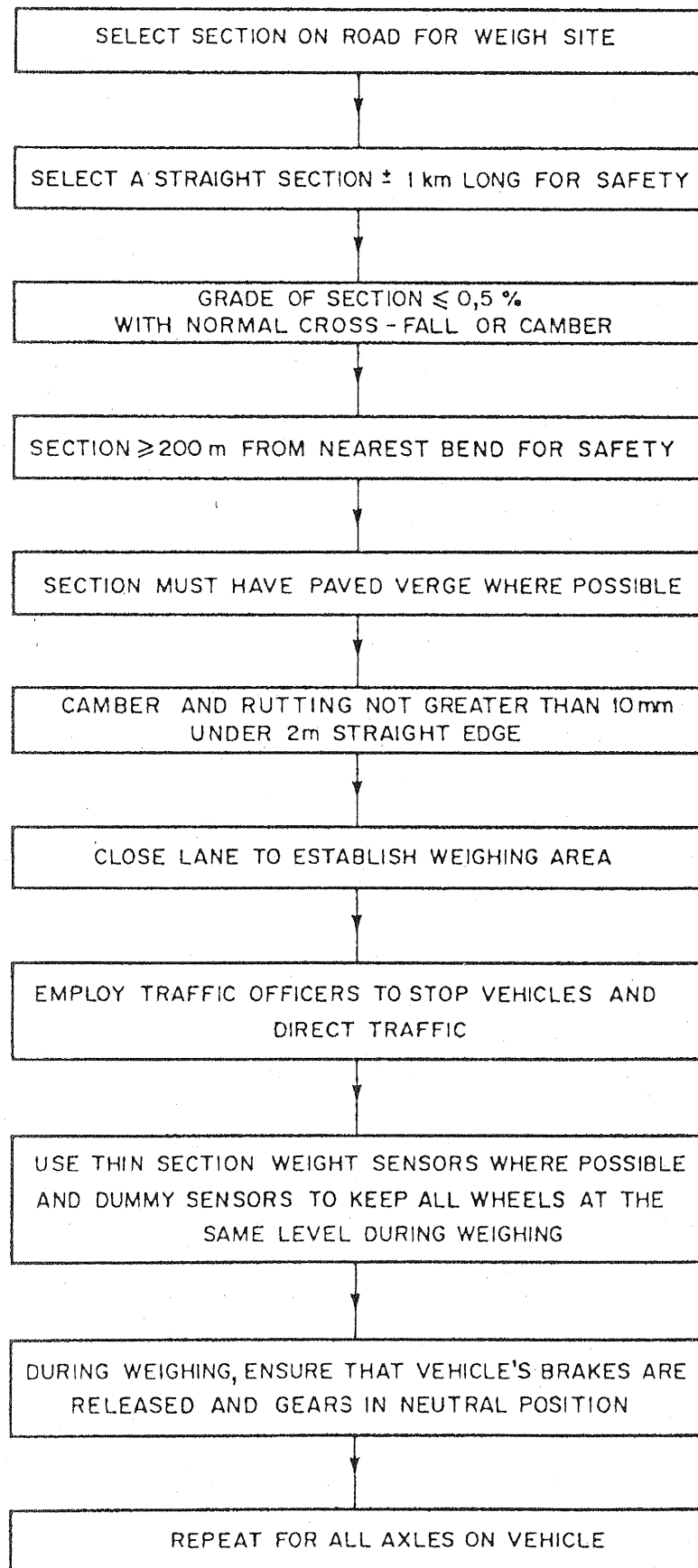


FIGURE 20

PROCEDURE FOR WEIGHING VEHICLES STATICALLY ON SELECTED ROAD

trailers such as the Payload Efficient Trailer or P.E.T. trailer. Vehicle weighing should be conducted on this site as summarised in Figure 19. Vehicle weighing can also be conducted on a normal road that has been partially closed as summarised in Figure 20.

- (d) All tyres on an axle must rest on the scale, or else incorrect readings could be obtained because of mass redistribution.

4.5 CALIBRATION OF EQUIPMENT

The calibration of these units is of the utmost importance, as measurements, even if taken with care, are only accurate if the equipment is correctly calibrated. When equipment is used for pavement design purposes, it may be calibrated as follows:

4.5.1 Platform scale or weighbridge

Permanently installed weighbridges or weighing platforms (Figure 17) are calibrated most reliably on site, with assized weights. The weights should register at least four points in the range 4 to 16 tons, and must be placed on the weighing area so as to avoid uneven loading of the scale.

4.5.2 Portable individual wheel weigher

Portable individual wheel weighers can best be calibrated on a static press that is known to be accurate. The weigher is placed on the base of the press with a rubber pad having a contact area of approximately 250 mm x 250 mm between it and the loading plate. The weigher is loaded two tons at a time from two to eight tons. This will then represent an axle load of 16 tons or an overload of nearly 100 %.

5 REFERENCES

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