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FACTORS INFLUENCING THE BEARING CAPACITY

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This Paper describes a brief state of the art of "Factors Influencing the Bearing Capacity." Factors dealt with here are traffic loads, subgrade soils, climatic conditions, pavement component materials and road geometry. Fundamental and well-established concepts of these factors are mainly described and individual studies are seldom refered to since the space is limited. Factors influencing the deflection measurement and theoretical analysis are also described briefly.

Finally, as a topic, the development of high viscosity asphalt is introduced. The most urgent problem in Japan has been to prevent the surfacing from plastic flow caused by high temperature and heavy load traffic. So far the use of high viscosity asphalt has been almost successful.

1. Introduction

This paper deals with the factors which influence the bearing capacity. There is rough agreement among paving technologists that the bearing capacity means soundness or load-carrying capacity of pavements. The strict definition of it, however, is rather uncertain as far as pavements are concerned.

Most agencies use equipment which measures a deflection and/or curvature as an indication of the bearing capacity. It must be noted that there are some failures which cannot be evaluated by deflection measurement. Pavement failures are divided into two types from the standpoint of deflection as an indication of the bearing capacity.

Type A;

1). cracking caused by load repetitions

2). rutting as an accumulation of permanent deformations of underlying layers

3). roughness caused by failures of underlying layers

Type B;

1). thermal cracking

2). rutting caused by plastic flow of asphalt mixes

3). lack of skid resistance

4). wearing

Failures of type A are characterized as the loss of bearing capacity in the pavement structures. In these cases the deflection is directly related to the bearing capacity. The AASHO (1) correlated these three failures with the present serviceability index (PSI). This paper deals with factors influencing the bearing capacity mainly taking these failures into consideration.

Failures of Type B result from temperatures (thermal cracking, plastic flow), materials (skid resistance) and spiked tires (wearing). These are characterized as surface distresses and other methods of measurement except deflection are required in order to reflect these factors on the load-carrying capacity.

2. Factors Influencing the Bearing Capacity

2.1 General Aspects

There are many methods of pavement design available. The design procedures vary depending to a large extent on the based and circumstances where they are developed. The principal factors involved in these design methods, however, can be summarized as follows:

1). traffic loads

2). subgrade soils

3). pavement component materials

4). climatic conditions

5). road geometry

The bearing capacity during the design period is dependent on these factors.

2.2 Traffic Loads

There is considerable variation in the axle load, vehicle speed and tire pressure that occurs on highway pavements. As it is nearly impossible to reflect all of the variables on the design, traffic loads are considered in terms of axle loads and the number of repetitions of the axle loads that the pavement must carry. Most agencies have established the methods of converting mixed traffic to equivalent axle loads for design purposes. There are many bases for equivalency, such as either calculated or measured stress, strain, or deflection in the pavement structure, or serviceability of pavement surface. In spite of these various bases, the equivalency factors are generally expressed by:

$$F_i = (W_i/W_o)^n \qquad \text{------------------------------} (1)$$

- F_i: the equivalency factor for the ith vehicle
- W_i: axle load of the ith vehicle
- W_o: standard axle load; Commonly used one in Canada, United States and Europe is 18 kips.

In the formula (1) n ranges 3 to 6 with most used value 4. One of widely used methods of obtaining the equivalency factors is that of presented in AASHO Interim Guide (2), in which the values of equivalency factors are tabulated as a function of the magnitude of load, the Present Serviceability Index and Structural Number.

2.3 Subgrade Soils

The load-carrying capacity of flexible pavements is largely influenced by the strength of subgrade soils.

Various test methods are used for evaluating subgrade strength. CBR test is most widely used among those methods. The agencies using CBR test for pavement design involve the Asphalt Institute, the National Crushed Stone Association, Great Britain, Switzerland, poland, Hungary, UNESCO and Japan.

The sample of CBR test is usually soaked in water for a period of four days to be saturated, which means that subgrade soil is tested under its worst condition. In certain cases, however, this standard method may lead to over design since the subgrade does not be always saturated. Therefore some agencies use their own revised methods. In Great Britain they use unsoaked test keeping the moisture content as likely to occur under the pavement.

Most rigid pavement designs are based on theoretical stresses in elastic slabs. The load bearing capacity mainly depends on the concrete slab structures in this case. But in the design and construction of subgrade, great caution must be taken against pumping.

2.4 Climatic Conditions

Typical climatic factors influencing the bearing capacity are as follows:

1). frost action
2). rainfall
3). temperature

A lot of investigators have studied about these factors in the laboratory or in the field since such factors have been recognized by pavement engineers to be important for design. However, their characterizations applicable to all circumstances have not been established yet. Most agencies take the factors into account in an empirical manner based on field observations and experiments.

Frost action, including thaw, is the most improtant factor in climatic variables. It is not so difficult to avoid frost action if frost susceptible soil can be replaced by good materials as deep as the frost penetration. But such full protection is rarely permitted for pavement engineers restricted by economics. Most agencies have established their own method of keeping frost action to a minimum under given economical conditions. It goes without saying that frost heave influence the bearing capacity, it is widely admitted that loss of subgrade support during the spring thaw is far more dangerous for pavement structures.

Rainfall itself does not cause any effects on the bearing capacity. But if water comes into subgrade and increases moisture content extremely, the whole system of pavement loses the bearing capacity. Water may come into pavement from cracks of surface, pavement edges and permeable surfaces. Frequent coming and accumulation of such water causes pumping in case of rigid pavement.

The factors affected by temperature are as follows:

1). thermal stress

2). stiffness of asphalt mix

3). frost action

If a slab is subjected to a temperature gradient, it will contract or expand. Restrained by its weight and the friction between the slab and underlying base, stresses are induced in the slab. Therefore, in the design of rigid pavement, the thermal stresses are taken into account and the methods of calculation and construction are well-established. In the design of flexible pavement, thermal stresses are neglected since asphalt mixes have the property of stress relaxation. Ordinary flexible pavements have no problem related to it, but in very cold areas, such as Canada and northern part of the United States, transverse cracking due to thermal stresses is frequently observed.

Temperature variations have no significant effect on the moduli of unbound materials, but strongly influence those of asphalt mixes. The Shell (3) have developed a procedure of estimating moduli of asphalt mixes from mean monthly air temperature for the calculation of permanent deformation.

2.5 Pavement Component Materials

Traffic loads are supported by "slab action" of concrete slab in the rigid pavement. Therefore material properties of concrete are controlling factors in this case. On the other hand, traffic loads are distributed to underlying layers in the flexible pavement. Accordingly the bearing capacity is influenced by pavement component materials.

The AASHO Road Test (1) introduced several important concepts. One of them is the layer coefficient which expresses the relative ability of a material to carry the loads as a structural component of the pavement.

The Japan Road Association (4) has established the design method of obtaining pavement thickness in terms of Ta which is similar to SN (Structural Number) of the AASHO. Ta represents the pavement thickness which would be required if the entire depth of the pavement were to be constructed of hot asphalt mixtures used for binder and surface course.

For the calculation of Ta, the following formula is applied.

$$Ta = a_1T_1 + a_2T_2 + \text{-----} + a_nT_n \qquad \text{------------------------(2)}$$

$a_1, a_2, ---, a_n$: coefficients of relative strength given in Table 1

$T_1, T_2, ---, T_n$: thickness of individual layers of pavement, cm

Coefficients of relative strength in Table 1 indicate in cm the thickness of hot asphalt mix used in constructing binder and surface courses, having a strength equivalent to 1 cm layer of pavement of other materials and methods of construction. Fifteen years have passed since the coefficients were issued and most pavement engineers admit that these values are appropriate.

2.6 Road Geometry

Road width and shoulder construction are the important factors concerning road geometry. Narrow roads force the traffic to pass the same position and the load is applied near the edge of shoulder. Transverse distribution of traffic loads increases the life of pavement. On the contrary regulation of traffic by lane mark tends to concentrate heavy traffic to the same position, which causes rutting.

Table 1 Coefficients of Relative Strength for Calculating Ta

Pavement Course	Method and Material of Construction Used	Conditions	Coefficient
Binder and Surface Courses	Hot asphalt mix for binder and surfase courses		1.00
Base	Bituminous stabilization	-Hot-mixed, Marshall stability:350kg or more	0.80
		-Cold-mixed, Marshall stability:250kg or more	0.55
	Cement Stabilization	-Unconfined compressive strength (7 days):30kg/m²	0.55
	Lime Stabilization	-Unconfined compressive strength (10 days):10kg/cm²	0.45
	Mechanically Stabilized Gravel and Slag	-Modified CBR:80 or more	0.35
	Hydraulic Mechanically Stabilized Slag	-Modified CBR:80 or more	0.55
	Penetration Macadam	-Unconfined compressive strength: (14 days):12kg/cm²	0.55
Subbase	Crusher-run, Slag, Sand, etc.	-Modified CBR:30 or more,	0.25
		-Modified CBR:20 or more, less than 30	0.20
	Cement Stabilization	-Unconfined compressive strength, (7 days):10kg/cm²	0.25
	Lime Stabilization	-Unconfined compressive strength (10 days):7kg/cm²	0.25

Note: Layer coefficient for any construction method or material other than thoselisted in Table 1 should only be adopted when based on established engineering experience.

Edge effects of traffic are so significant that pavement designers should pay attention to proper drainage and paving of shoulder.

2.7 <u>Comparison of Several Design Curves</u>

So far various design curves have been published. Although major factors involved in those design curves are not so different, pavement thicknesses derived from them vary considerably.

Figure 1, 2 are examples of difference in case of flexible pavement. The discussion of choosing the best design is meaningless since every design is considered best under its circumstances backed up by a lot of laboratory and field experiences and/or theoretical bases.

3. Factors influencing the deflection

3.1 General Aspects

In 1962 the Association of Asphalt paving Technologists selected the symposium subject as "Flexible Pavement Behavior as related to Deflections". It is interesting to note that the deflection measurement was primarily used in research at that time.

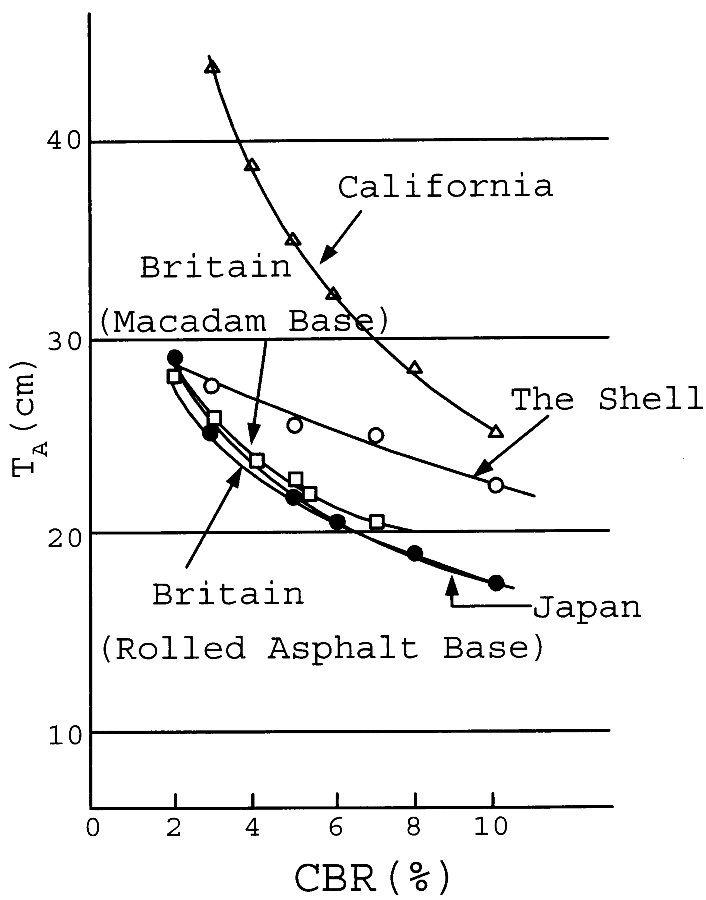

Fig.1 Comparison of Several Design Curves (1)

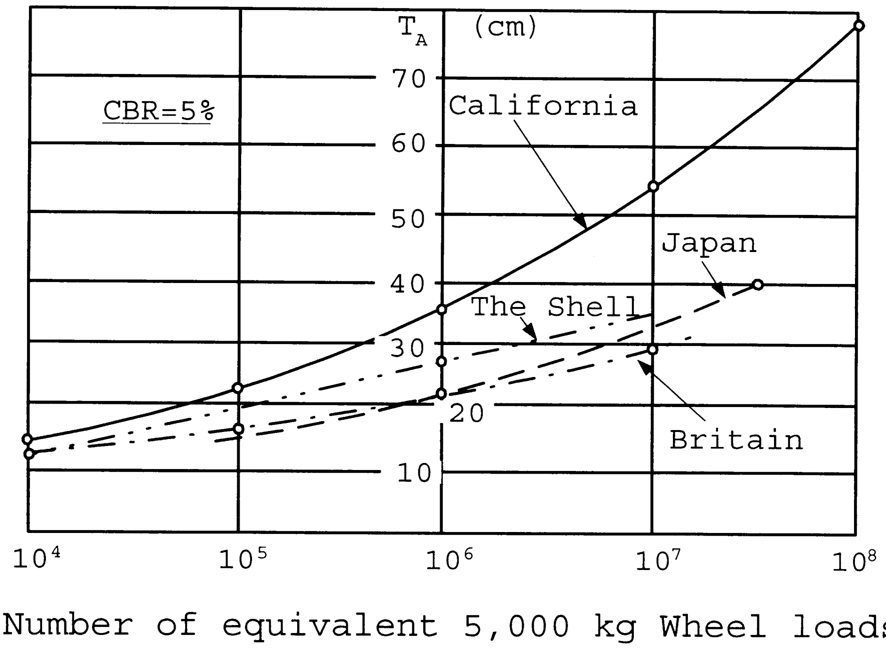

Fig.2 Comparison of Several Design Curves (2)

Twenty years have passed since then and now the deflection measurement is widely used for the estimation of pavement conditions and for the design of overlay. Although Benkelman Beam has been the most fundamental tool of measuring, various equipments, such as Dynaflect, Deflectograph and Falling Weight Deflectometer, have been developed.

This chapter deals briefly with the factors influencing the deflection measurements. They are:

1). loading conditions
2). subgrade soils
3). pavement components
4). temperature
5). methods of measurement applied

The factors influencing the theorectically calculated deflections are refered, too.

3.2 Loading Conditions

Various loads are applied for deflection measurement. Obtained values are influenced by following conditions.

1). magnitude of loading: varies widely
2). type of loading: dynamic or static
3). type of contact: rigid or flexible
4). shape of contact: circle, ellipse or rectangle

Loading condition of a equipment consists of the combination of these parameters. Relationship among the parameters and equipments has been investigated experimentally, which will be discussed in the following session.

3.3 Subgrade Soils

Subgrade strength varies seasonally according to the moisture content in soils. Measured deflection is directly affected by this seasonal change of subgrade strength since the subgrade displacement occupies a large part of pavement deflection.

3.4 Pavement Components

A small deflection does not always guarantee a long life of the pavement since deflection is a temporary response of the pavement. For instance the deflection of a pavement with cement stabilized base is generally smaller than that with gravel base, but the life of the two is not so easily ranked. This may be due to the difference of permissible strain of the two. Consequently deflection criteria cannot be discussed without considering pavement components.

3.5 Temperature

As stated previously in 2.4, the stiffness of asphalt mix is influenced extremely by temperature. Consequently the deflection varies according to the movement of temperature. Since the temperature of asphalt surfacing changes from time to time, the deflection cannot be fixed. Many agencies, however, have found temperature adjustment factors. One of widely used methods for Benkelman Beam is described in Manual Series No.17 published by the Asphalt Institute (5).

3.6 Methods of Measurement Applied

Many different types of measuring equipment are used to Obtain deflection data. It is a very difficult task to correlate these data. Even if the discussion is limited to Benkelman Beam, many different methods are used. Major parameters are beam geometry, measuring position, speed of vehicle, axle load and tire pressure. Moreover shape of deflection curve influences the measurement, too.

3.7 Factors Influence the Theoretical Value of Deflection

Multi-layered elastic theory has been used for calculating the theoretical value of deflection. Many investigators have compared theoretical value with measured value. Some say they have found coincidence between the two, while others not.

Major factor controlling the calculated value is moduli of the pavement layers including subgrade. Different estimation of moduli leads to different conclusion. Another factor is the estimation of loading conditions. Only static load is used in the calculation though moving or dynamic load is applied in the measurement.

The influence of deflected basin on the comparison between the two has been also pointed out by many investigators. This is most significant when measurement is applied for the pavement with strong structure on weak subgrade.

4. Development of High Viscosity Asphalt in Japan

This chapter describes a brief introduction to high viscosity asphalt developed recently in Japan. Road situation and climatic conditions are introduced beforehand for better understanding of background. Most parts of description are derived from English version of "Manual for Design and Construction of Asphalt Pavement" published by the Japan Road Association.

Japan has a public road network approximately 1.1 million kilometers in total length, out of which 0.44 million kilometers are paved. Flexible pavements account for 90% of all pavements.

The principal characteristics of road traffic in Japan are the high percentage of cargo trips and the high percentage (as high as 20%) of large size vehicles, including a considerable volume of vehicles having an axle load of 20 tons or more.

The climate in Japan is characterized by heavy annual precipitation and large annual temperature differences. Thus, pavement surface temperature generally rises very high during summer days. In the case of asphalt pavements, high surface temperature reaching or surpassing 60°C may occur successively for 6 to 10 days in a row during the peak season, and the maximum may rise as high as 70°C.

Heavy vehicle traffic and high temperature have caused the plastic flow of asphalt surfacing. Rehabilitation of most major roads has been limited to cutting and overlaying method owing to plastic flow with no cracking. Semi-blown asphalt having absolute viscosity at 60°C over 10,000 poise was first developed nearly ten years ago. Since then field experiments have been carried out at

Table 2 Requirements for Semi-blown Asphalt

The semi-blown asphalt shall be homogeneous and free of water, shall not foam when heated to 180°C, and shall satisfy all the following requirements.

Characteristics	Values
Viscosity at 60°C, poise,	10,000±2,000
Kinematic viscosity at 180°C, max, cSt	200
Mass change by thic-film oven test, max., %	0.6
Penetration at 25°C, 100g, 5sec., min.	40
Solubility in trichloroethane, min., %	99.0
Flash point, COC, min., °C	260
Specific gravity at 25°C, min.	1.000
Ratio $= \frac{\text{Viscosity at 60°C after thin-film oven test}}{\text{Viscosity at 60°C before thin-film oven test}}$ max.	5

Sources: Japan Road Association, Japan Asphalt Institute

more than a hundred sections. It has been proved that average plastic flow at test sections is half of that observed at ordinary sections. Standard properties of semi-blown asphalt are shown in Table 2.

References

1. "The AASHO Road Test" Special Report 61E, Highway Research Board, 1962

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5. Asphalt Overlays and Pavement Rehabilitation, The Aspahlt Institute, Maryland, 1977