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In Norway, the bearing capacity of roads is determined on the basis of measuring the layer thickness (index method) or by deflection measurement. The layer thickness measurements give us the bearing capacity of the road over the entire year, while deflection measurement shows the bearing capacity at the time of measurement. Deflection measurements are primarily used to determine the bearing capacity in the summertime, since this hardly varies from year to year. The purpose of this article is to discuss the uncertainties of using these methods.

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ROAD BEARING CAPACITY AS DECIDED BY DEFLECTION MEASUREMENTS AND THE INDEX METHOD*

by

GEIR REFSDAL, Chief Engineer, Road Laboratory, Oslo

SUMMARY

In Norway, the bearing capacity of roads is determined on the basis of measuring the layer thickness (index method) or by deflection measurement. The layer thickness measurements give us the bearing capacity of the road over the entire year, while deflection measurement shows the bearing capacity at the time of measurement. Deflection measurements are primarily used to determine the bearing capacity in the summertime, since this hardly varies from year to year.

The purpose of the article is to discuss the uncertainties of using these methods, and emphasizes the following:

Deflection Measurement

- When the deflection measurements are used, no consideration is given to the curvature of the road covering, even though this curvature will obviously be of great importance for the useful life of the road covering.
- There is no simple correlation between various types of measurement equipment. Thus, the result may be dependent on the type of measuring equipment used.
- Is it possible that measurements taken at an arbitrary time during the summer will give a sufficiently good representation of the bearing capacity of the road in summertime?

Layer Thickness Measurement

- Is the influence of materials with inherent frost damage risk being exaggerated?
- The material coefficients are in reality not constant but dependent of location, etc.
- Could it not be that tire pressure is really responsible for the break-down of a road surface? If the elasticity of the construction is located at a high point, such as is often the case when the soil is thawing out, this would be an applicable reason.

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*Source: Norwegian Road Research Laboratory, Gaustadalleen 25, Postboks 8109, Oslo Dep.

It is possible that in the future, deflection measurements will be made in the spring thaw period rather than in the summer for purposes of determining the dimension of reinforcements. The new road standards (1980) already make it possible to use a variety of measurements to correct the dimensions arrived at by the index method.

WHAT DOES "BEARING CAPACITY" MEAN?

The expression "bearing capacity of a road" comprises expectations that the road will tolerate repeated loads (expressed, for instance, in equivalents of 10 ton axles) over an extended period of time ("dimension period", e.g. 10 years) without deteriorating below an acceptable limit.

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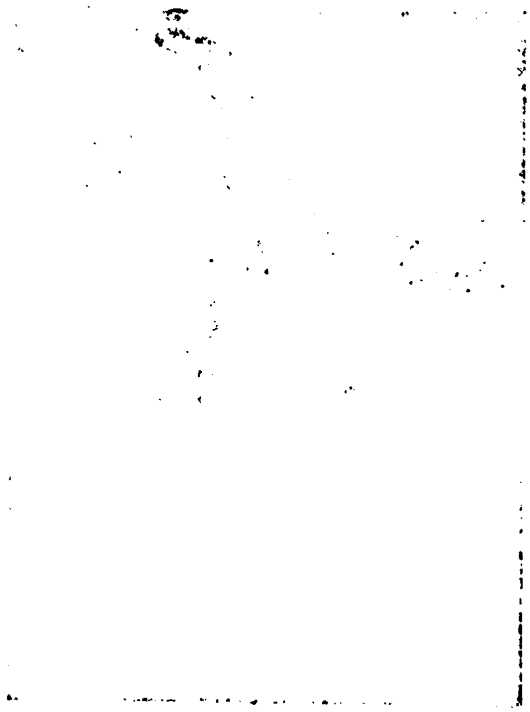


Frost cracks will often appear even if the bearing capacity design is carried out according to the standard specifications.
Photo: G. Refsdal

In Norway, we need to differentiate between the concepts of
- summer bearing capacity
- spring thaw bearing capacity
- year round bearing capacity.

The summer bearing capacity rarely shows great variations from year to year, but it may nevertheless be somewhat affected by abnormal precipitation conditions. The spring thaw bearing capacity may vary considerably from one year to the next. This applies specifically for underdimensioned roads or when materials with inherent frost risk (i.e. sensitive to water) are used in the construction.

A year round bearing capacity is assumed to apply for a complete dimensioning period without introduction of axle load restrictions, and it must have a built-in consideration of the bearing capacity that exists during those years when the spring thaw is particularly difficult. Statistically, it is assumed that the real spring thaw bearing capacity will be below the year round bearing capacity only one out of ten winters.

	Axle load		Useful life
	Spring	Summer	
Assumed "correct":	6t	10t	10 years
If:	8t	10t	7 years
If:	10t	10t	3 years
Assumed "correct":	8t	10t	10 years
If:	10t	10t	8 years

If the real bearing capacity of a road in the spring thaw period is lower than the allowable axle load in this period, the service life of the road can be drastically shortened.

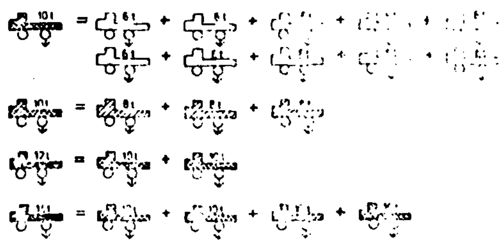
HOW IS TRAFFIC LOAD EXPRESSED?

For dimensioning a road we need to express its traffic load. In Norway, as in several other countries, the load is expressed in equivalent numbers of 10 ton axles per driving section during the dimensioning period. The effect of each axle is expressed by the break-down effect it is assumed to have as related to that of a 10 ton axle. This ratio is expressed by an "equivalence factor". The equivalence factors used in Norway have been taken from an American road experiment in the 1960's (AASHO).

Axle load, P, in tons	6	8	10	12	14
Equivalence factor, E	0.1	0.4	1.0	2	4

Axle loads and their equivalence factors

The effect of: Corresponds to:



Examples of axle loads with equivalent damaging effect.

In the AASHO experiment it was found that the equivalence factor for the axle load P, compared with a 10 ton axle, could be expressed with the equation

$$E = \left(\frac{P}{10} \right)^n$$

where n equals 4. For the break-down of the surface construction in its entirety, this is probably a reasonable value. n = 4 is used in the dimensioning systems of several countreis for lack of a better basis. Magnitudes both below and above 4 have been found in other countries, although after significantly fewer tests. In the Scandinavian STINA project it was investigated whether the effect of permanent deformations in the substratum on the break-down of the road would be correspondingly dependent on the load. It was found that in respect to the influence of the substratum, a few very large and heavy loads will have major effect, while a great number of large and average loads mean less for the break-down that the 4-power rule would indicate. If converted to a specific power, the STINA results would approximately correspond to n = 16 (1).

There is no completely "correct" power. The n value will be affected by road construction as well as by substratum and climate.

In order to define the traffic load, N, in the dimensioning process, the starting point is the annual daily traffic of heavy vehicles. For a given permissible axle load, the distribution of axle loads among the heavy vehicles is estimated, and it is assumed that on the average, each heavy vehicle has 2.4 heavy axles. Further, it is assumed that there is an annual increase of 2.0%

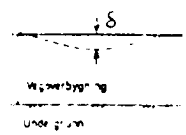
in the average daily traffic over a year. It can be mentioned as an example of how an error in the N value affects the permissible axle load, that if the real traffic load is twice as high as calculated, the permissible axle load should have been reduced by 2 tons, provided the dimensioning period remains the same.

HOW IS THE BEARING CAPACITY DETERMINED?

Not only does the bearing capacity vary throughout the year, but it varies from year to year as well. If we wish to express the bearing capacity on the basis of measurements, deflection measurements are appropriate. Such measurements express the bearing capacity at the time of the measurement.

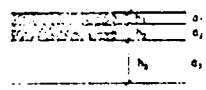
We use deflection measurements (with Benkelman beam, Dynaflect, or La Croix Deflectograph) to determine the summer bearing capacity. It is possible to establish the spring thaw bearing capacity as well by means of deflection measurement, but there are some practical problems in so doing, since the measuring period is so short. The bearing capacity can also vary considerably from one spring thaw to the next.

Determination of summer bearing capacity



[Surface layer]
[Substratum]

Determination of spring thaw bearing capacity

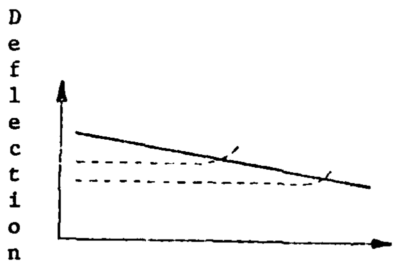


The summer bearing capacity can be established by deflection measurements. The spring thaw bearing capacity can be established by use of classification of the materials in the pavement and measurement of layer thicknesses (index method).

The spring thaw bearing capacity is therefore currently determined on the basis of opening the surface, classifying the materials, and measurement of layer thicknesses (index method). By comparing this structure with the dimensioning tables of the road standards, the bearing capacity of the road can be determined.

SUMMER BEARING CAPACITY

The summer bearing capacity is determined by means of deflection measurements of the road surface. The deflection of a road surface will remain reasonably constant for a long period of time (dimensioning period) until it will increase sharply, which indicates an accelerating break-down of the road. Correlations of the type shown in the figure have been established in many countries, including Norway.



Number of equivalent 10-ton axles, N

Correlation between deflection and the accumulated axle loads, expressed in terms of equivalent 10-ton axles.

The manner of utilizing the method in Norway can be criticized in some respects:

- The data base (correlation axle load / deflection / useful life) is old, but it nevertheless does not seem to be dramatically different from that used in other countries.

- The method does not differentiate between various types of tires. The experience basis has been obtained only from roads with asphalt surface. Would not the curvature of the road surface, e.g. on a gravel road, be of some importance for the result? And what about the material pressed up between the twin wheels of the measuring vehicle when the Benkelman beam is used?

- Disregarding the type of road surfacing, it is natural that the curvature of the surfacing must mean much for the useful life of the road covering. Thus, whenever possible, we should measure the surface curvature as well as the total deflection. It is to be expected that such measurements will become successively more frequent.

- We use different types of measuring equipment: equipment types different in principles of function, but also heavy and light equipment. The correlation between equipment types cannot remain constant for all road construction types, but for the sake of simplicity, we nevertheless utilize one simple correlation.

- Deflection measurement gives an expression of bearing capacity at the time of measurement. Would there not be enough variations in this value over the year (summer/fall) and from one year to another to create some major inherent errors in one measurement made on one day? High values may be obtained, particularly on roads with unsatisfactory bearing capacity, but this does not normally occur. Would it be possible to produce a correction factor that gave special consideration to precipitation conditions?

- The deflection in the outside tracks is used for dimensioning purposes, and this is frequently some 20% greater than that in the inner tracks. It is thus probable that we overdimension great portions of the cross-section, particularly for roads with narrow shoulders where the bedding is unsatisfactory.

YEAR ROUND BEARING CAPACITY

In principle, it is also possible to utilize deflection measurements for determining the bearing capacity in the spring thaw. The possibility to obtain accurate measurements in the spring thaw period is limited due to the availability of measuring equipment, particularly if extensive records are desired. Furthermore, the bearing capacity will be greatly depending on how far down into the road the frost extends and on the progress of subsequent thawing.

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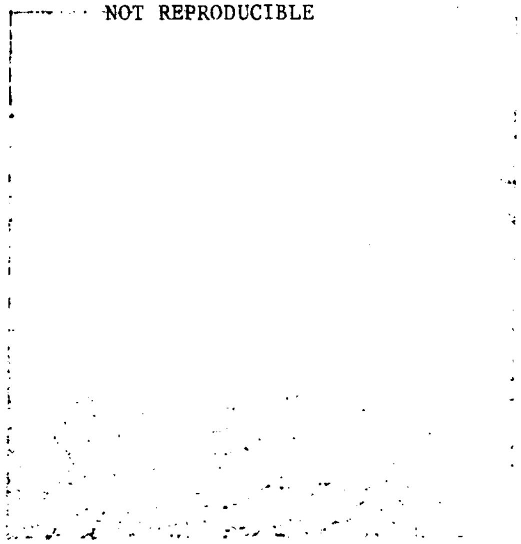

The bearing capacity in the spring thaw can principally be established with deflection measuring equipment. The problem will be to find the lowest bearing capacity within this short period and to adjust, if required, if the spring thaw period is considered not representative.
Photo: R. Eirum

In Norway, an index system is used for dimensioning of new roads. The system is also used to evaluate the bearing capacity of an existing road. In such cases, the year round bearing capacity is determined, i.e. the permissible axle load applicable even to the "worst" spring thaw which can statistically be expected during the dimensioning period. For an existing road, required reinforcements can also be expressed by means of an index value.

The use of the index system for determining the permissible axle load in the spring thaw period has several disadvantages:

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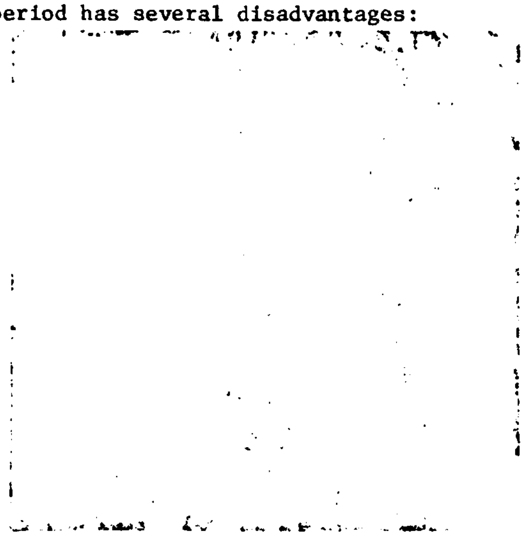

In the index system, each material is given a material coefficient, which is supposed to be a constant. This coefficient will actually vary, not only due to variations in material quality, but also with the material located above and below.

Photo: R. Eirum

- The bearing capacity during the spring thaw varies from year to year. The index system gives the bearing capacity for a "critical spring thaw". Normally, the real bearing capacity in any spring thaw will be between the bearing capacity calculated from index measurements during the spring thaw [one line missing in the text. Reconstructed continuation: By means of additional] measurements on reference sections of the road during the spring thaw, it would be possible to calculate a correction factor which would yield the bearing capacity for a critical spring thaw as well.

- Is the frost risk of certain materials exaggerated? With good drainage (filling) and low water quantities in the vicinity, frost risk materials need not have any undesirable effects. Such conditions are somewhat too fleetingly treated in the index system.

- Material coefficients expressing the load distribution capacity of road construction materials are assumed to be constant, indeppndent of both potentially great material variations and of other materials in the vicinity. In reality, adjacent materials have great influence on the load distribution capacity of a material.

- Tire pressure can conceivably have greater effects than axle load - at least early in the spring thaw period. No consideration is given to this.

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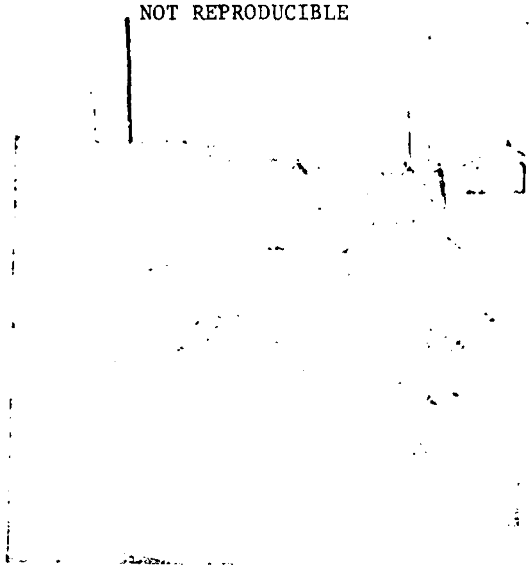

In the spring thaw period, the bearing capacity will differ from one year to another. The index system gives the bearing capacity for a "critical" spring thaw period which statistically should appear only one year out of ten. The real bearing capacity will normally be between the summer bearing capacity as found from deflection measurements and the bearing capacity as given by the index system.
Photo: R. Eirum

When reinforcements are being discussed - would it not be possible to perform deflection measurements in the spring thaw period and use these for correction purposes in the dimensioning? The proposed new road standards (1980) makes this possible. In the future, it may be possible to make direct use of deflection measurements.

When restrictions on the axle load are introduced during the spring thaw, the rationale is that the deflections should not be greater than can be permitted in the summertime. Should it be permissible that a higher percentage of the break-down of the road occurred in the spring thaw period?

FACTORS THAT ARE NOT CONSIDERED IN THE DIMENSIONING

In addition to the error sources inherent in the measurement methods and the regulations concerning traffic load, there are also other factors that are not considered in our dimensioning calculations:

- Wearing of Grooves. For annual daily traffic loads above 3000 vehicles/day, the wearing of grooves seems to determine the rate of surface renewal. In such cases, the dimensioning ceases to be of interest insofar as new road surfaces can be easily rebuilt well above the standard requirements. (Use of "soling" on the surface will not, however, increase the index value of a road.)

- Driving in Grooves. The extent of groove driving is highly dependent on the width of the road. This will affect the useful life of the road.

- In the wintertime, when the superstructure of the road is frozen, it is possible to get higher utilization of the superstructure in terms of bearing capacity without consequences in respect to reduced useful life. This possibility is not being utilized.

Inherent in our dimensioning system is also a selection of a susceptibility level for the dimensioning, i.e. the degree of underdimensioning that can be allowed. The road standards assume that 10% of a road section may be underdimensioned. If the susceptibility is changed, the results may vary widely using the same dimensioning system and the same experiental basis.

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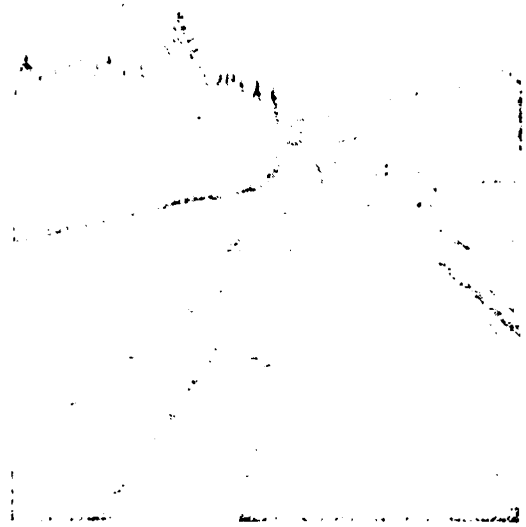

During the winter period, the real bearing capacity of the roads is much higher than the legal axle load.
Photo: G. Refsdal

STRUCTURAL DIMENSIONING - BETTER THAN GOOD JUDGEMENT?

The usefulness of bearing capacity measurements and index-based structural dimensioning can be questioned, considering the objections that have been expressed against our current system of establishing permissible axle load and also in respect to all the uncertainties inherent in the initial parameters for structural dimensioning. However, we do need a standard basis for the structure of the road, and we will have to tolerate deviations potentially resulting in the useful life of the road differing from its assumed useful lifetime.

Within the framework of the STINA 2 project, all parameters used in the dimensioning have been studied, and it has been explored how they affect the result of the dimensioning, individually and in combination, when consideration is given to the uncertainties inherent in the parameters (2). The study revealed that the greatest uncertainty can be found in the dimensioning model itself, and this applies to the general method of dimensioning. The results of STINA 2 also indicate that a dimensioning which is correct to 1 or to 10 cm is less important than proper dimensioning of the materials utilized in the structure so that these can be fully utilized in a later repair of the road as well. It is at that time that we have to pay the bill if the materials have been unsatisfactory. Bad materials will result in increased deflection as well as in reduced index value. By comparison, the cost caused by potential initial underdimensioning must be characterized as modest.

Possibly, the development may be that the index system is retained for dimensioning of new road and for reinforcement of existing roads. However, for reinforcement, the advisable axle load for the road will probably be determined not by measurements of layer thicknesses but by means of deflection measurements in the spring thaw period or in the summer. Thereafter, the index system may be used to determine the necessary reinforcement effort in order to go from advisable to desirable and permissible axle load.

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