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THE USE OF "STRUCTURAL ADDITIVES" IN RAILWAY TRACK BASE COURSES

L'EMPLOI «D'ADDITIFS DE STRUCTURE» DANS LES COUCHES SUPPORT DE VOIES FERREES

STRUKTURVERBESSERNDE MASSNAHMEN BEI DER ERRICHTUNG VON GLEISKÖRPERN

The modern technique of maintaining the geometry of the railway track by heavy mechanized tamping and adjustement is not suitable for intermittent operations ; moreover it proves ineffective when, in long term, the ballast course becomes polluted (rise of fines from the subgrade, attrition of aggregates, etc...). Special care should therefore be taken in the laying of base course structures on argillaceous or silty soils, especially when the work is carried out in rainy weather. In this respect, the use of structural additives such as geotextiles has undeniable advantages (the laying of the courses is greatly facilitated, there is better conformity to the geometry of the courses and the gradient towards the drainage system, etc...). When the track is in service, this is reflected in fewer levelling operations and an increase in the "duration of tampability" of the ballast.

Die modernen Techniken der Ausrichtung der Gleislage zeigten sich ineffektiv, wenn das Schotterbett verschmutzt ist. Es ist deshalb besondere Sorgfalt beim Einbau der Tragschicht bei körnigen und schluffigen Böden zu legen, besonders bei Regenwetter. Der Einsatz von strukturverbessernden Einbauten wie Geotextilien hat unlengbare Vorteile (einfacherer Einbau der Tragschicht, besseres Einhalten von Gleiskörpergeometrie und Quergefälle etc.). Während des Betriebes führt dies zu einer Vergrößerung der notwendigen Sanierungsintervalle.

I. INTRODUCTION

These problems of railway track base courses have been examined in detail in recent years in the context of the International Union of Railways (I.U.R.) (2), (5), and are the subject of a consolidated document (4) entitled IUR Memorandum 719 R "Earth Structures and railway track base courses". The concepts of the S.N.C.F presented here are of course in accord with the recommendations of the IUR document, but in addition they take account of factors specific to the French context (climate, geology, track maintenance strategy, etc...).

II. CONSTRUCTION OF BASE COURSES

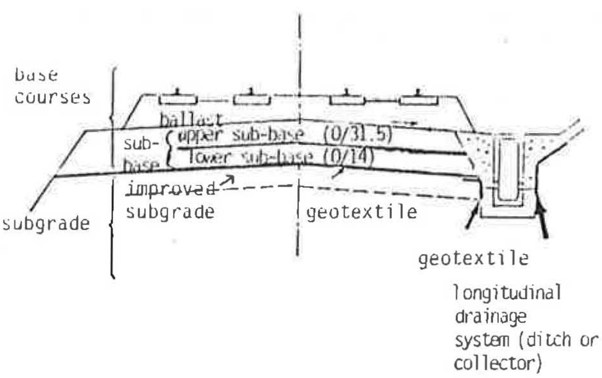


Figure 1. Example of a cross-section.

The base courses of a railway track (fig. 1) comprise :

- the ballast course (25/50 broken stone).
- the sub-base, consisting of well-graded aggregates (On existing tracks it usually consists of a mixture of ballast, sand, cinders and soil.)and, if need be, various additives (geotextiles, geomembranes).

These base courses rest on the subgrade. The upper part of the subgrade is called the improved subgrade ; this part is slightly more compacted than the subgrade below it (100 % OPN instead of 95 %), and sometimes it differs also in respect of the nature of the soil.

III. THE ROLL OF BASE COURSES

The base courses must distribute over the subgrade the loads transmitted by the sleepers and contribute to the longitudinal and lateral stabilization of the track.

The ballast course, by reason of its particular particle size distribution, performs the following functions.

- It ensures the rapid evacuation of rainwater.
- It constitutes an effective vibration damper.
- It allows of rapid adjustment of level and alignment by tamping and dressing.

The sub-base :

- Protect the upper part of the subgrade from erosion which may result from perforation by fragments of ballast, and from the effect of rainfall (it must be transversely inclined).

- Ensures, in conjunction with the ballast, the protection of the subgrade from frost.

- Complements the action of the ballast in transmitting loads to the soil.

IV. THE TRANSMISSION OF LOADS : THICKNESS OF COURSES

The intensity of repeated stresses on the subgrade must be compatible with its bearing capacity. In this respect the base courses must be correctly structurally designed in function of the following parameters :

- Nature of the traffic carried by the track *.
- Type of sleepers.
- Nature of the soil.

Lines are classed as follows in IUR groups 1 to 9, in decreasing order, defined in IUR memoranduũ 714 R. The traffic is "nominal", the tonnages being weighted according to speed on the line and the comparative wear and tear of various kinds caused by rolling stock.

	1,5	3,5	7	14	28	50	85	120	thousands of tonnes per day
9	8	7	6	5	4	3	2	1	

Nominal traffic IUR group

Where the nature of the soil is concerned, we have to consider, in function of the geotechnical category and hydrogeological conditions, the following four grades of soil QS_i (see fig. 2) :

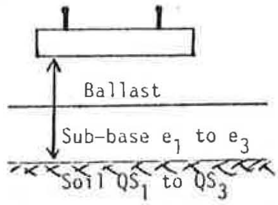
Soil classification (geotechnical identification)	Soil grade
Q.1 loose organic soils Q.2 fine soils (containing more than 15 % of fines (1) wet, swollen and hence not compactable. Q.3 thixotropic soil (2) (e.g; quick rock) Q.4 soluble materials (e.g. soil containing rock salt or gysium) Q.5 polluting materials (e.g. industrial waste) Q.6 composite soils, "mineral and organic" (2)	QS_0
1.1 soils containing more than 40 % of fines (1) 1.2 highly evolutive rocks : e.g. very brittle charlk of pd<1.7 t/m3 marl weathered shale	QS_1
1.3. soils containing 15 to 40 % of fines (1) 1.4 evolutive rocks : e.g. not very brittle charlk of pd <1.7 t/m3 unweathered shale 1.5 soft rocks e.g. dry Deval < 6 and Los Angeles > 33	(3) QS_2
2.1 soils containing 5 to 15 % of fines (1) 2.2 sand containing less than 5 % of fines (1) but uniform 2.3 fairly hard rock (e.g.≤6 dry Deval < 9 33 ≥ Los Angeles>30	(4) QS_2
3.1 soils containing less than 5 % of fines (1) 3.2 hard rocks (e.g. dry Deval ≥ 9 Los Angeles ≤ 30)	QS_3

Fig 2. Soils of grade QS_i

(1) Analyses of particle size distribution enabling these percentages to be evaluated are carried out on 60 mm sreened material. The percentages indicated here are orders of magnitude (procedures differ somewhat from one railway system to another) ; they can be increased by as much as 5 %, provided thaht the analyses are carried out on a sufficiently representative number of samples.
(2) Some systems place these soils in grade QS_1 in certain cases.
(3) These soils may be of grade QS_2 if it is certain that hydrogeological and hydraulogical conditions are satisfactory.
(4) idem QS_3 "

QS_0 - "unsuitable" soil for construction base courses on it must be replaced, or treated with binders;
QS_1 - "poor" soil.
QS_2 - "average" soil.
QS_3 - "good" soil.

The thicknesses (mesured under the sleepers) (7) of the ballast + sub-base are given in fig.3.



Values of "c"
0 for a normal structural design
0.10 m in exceptional cases, for difficult operations on existing tracks of IUR groups other than 7, 8 and 9 not carrying passenger traffic.
0.15 m in exceptional cases, for difficult operations on existing tracks of IUR groups 7, 8 and 9 not carrying passenger traffic.

Values of "d"
0 when the maximum nominal axle load of the vehicles towed is 200 kN
0.05 m when this load is 225 kN

$$e_1 = 0.70 \text{ m} - a + b - c + d$$
$$e_2 = 0.55 \text{ m} - a + b - c + d$$
$$e_3 = 0.45 \text{ m} - a + b - c + d$$

Values of "a"
0 for tracks of IUR groups 1 and 2 or tracks of V 200 km/h
0.05 m tracks of IUR group 3
0.10 m for tracks of IUR groups 4, 5 and 6, and 7, 8 and 9 carrying passenger traffic.
0.15 m for tracks of IUR groups 7, 8 and 9 not carrying passenger traffic.

Values of "a"
0 for tracks of IUR group 1 and 2 or tracks of V 200 km/h
0.05 m for tracks of IUR group 3
0.10 m for tracks of IUR groups 4, 5 and 6, and 7, 8 and 9 carrying passenger traffic.
0.15 m for tracks of IUR groups 7, 8 and 9 not carrying passenger traffic.

Values of "b"
0 for wooden sleepers of 2.60 m
$\frac{2.50-L}{2}$ for concrete sleepers of length L. (b and L are expressed in metres ; b may be negative if L ≥ 2.50 m).

Fig. 3. Thickness of ballast + sub-base (e_1 to e_3) for soils of grade QS_1 to QS_3

V. STANDARD BASE COURSE STRUCTURES (7)

The foregoing considerations have led to the establishment of "standard base course structures" detaied in fig. 4
It may be noted that on poor soil QS_1 (clay, silt, marl, etc...) or on average soil (gravelly and sandy soil containing a high proportion of fines), a geotextile is always interposed between the sub-base and the soil. Otherwise it would be necessary to lay an extra thickness of sub-grade to allow for :

- The inevitable contamination of a certain thickness of the course below
- Deeper rutting of the soil during laying.

Figure 4 shows the three types of base course structures

5.1. Conventional structures (fig. 4a)

These structures consist mainly of aggregates with well-defined particle size distribution, obtained from quarries or gravel pits. Technically, they have a very wide field of application. Even under poor hydrological or climatic conditions, there is no difficulty in laying them ; a geotextile is unrolled in contact with the sensitive soil, then the first layer of well-graded aggregate is spread, with the trucks running on the material that has been dumped ; the presence of the geotextile prevents excessive rutting of the improved subgrade despite the deformability of the subgrade, and subsequently ensures (thanks to the hydraulic transmissivity specific to the nonwoven geotextiles used) a certain homogenization of the water content of the soil over the whole surface of the subgrade.
This technique was employed as early as 1972 for the construction of lines serving new towns in the Paris suburbs, and proved completely satisfactory. Yet the geological and hydrogeological conditions were very unfavourable : cuttings dug down to the level of the water table, excavation floors in fresh marl, etc...
Type of geotextile used : The S.N.C.F uses (3) a continuous filament needled geotextile such as Bidim grade (400 g/sqm).

5.2. Structures with built-up improved subgrade (fig. 4b)

These structures incorporate an improved subgrade of better quality than the subgrade itself ; the material may be different, or the same material as the subgrade may be treated with hydraulic binders. This solution may be more economical on large-scale working sites (needing less material from quarries or gravel pits), but it is only valid if the following conditions are met :
- The subgrade has a low water content as the time of the work, otherwise there will be rutting and the course thicknesses and transverse inclinations will not be conformed to. The solution cannot be adopted when the subgrade contains a water table or an internal circulation of water, or when the work is carried out in rainy weather.
- The soil of the built-up improved subgrade is homogeneous and does not contain locally a percentage of fines liable to bring the soil grade down to a lower category.

5.3. Structures incorporating a geomenbrane (fig. 4c)

On a poor subgrade (fine loose soil or soft rock liable to weathering) this solution makes it possible to reduce the overall thickness of the base courses, because the subgrade is totally protected from rainwater, and hence the quality of the soil in question can be considered as having been raised to the grade above. Of course, this is not entirely the case when the soil contains a water table or an internal circulation of water, in which case special care must be taken in lowering the water table and draining the water to prevent it being trapped under the membrane.
In the case of a new track, it is wise, in addition to the above measures, to provide a drainage layer under the geomenbrane (fig. 4c).
In the case of an existing track, during localized operations using this technique it is scarcely possible to provide a drainage layer ; an attempt must therefore be made to previously clear the ballast, to as shallow a depth as possible, so as to preserve the pre-existing structure under the geomenbrane. Furthermore, the work must be done in such a way as to avoid deterioration of the geomenbrane when the track is surfaced by a mechanical tamper (prior laying of a compacted hydrocarbon layer).
Type of geomembrane used : the geomembrane used by S.N.C.F (8) is the Colétanche NTP 4, which is an impervious bituminous membrane made by impregnating a nonwoven Bidim in the factory with a very hard bitumen with the addition of a limestone filler. This geomembrane is not easily perforated and can thus be safely placed close to the ballast course.

VI. LONGITUDINAL DRAINS

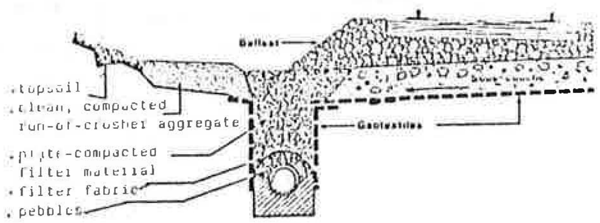


Fig 5. Drainage system

The use of geotextiles is also very important in longitudinal drainage systems on either size of the subgrade. They greatly facilitate the filtration (fig. 5) ; the fill material is a simple mat, whereas formerly it was necessary to use material of successively increasing particle size distribution.

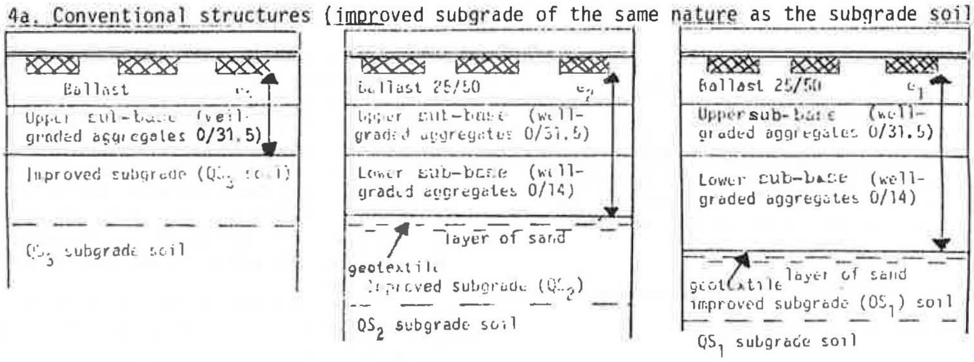
VII. CRITERIA OF QUALITY OF A RAILWAY TRACK BED

7.1. The notion of the coefficient of bed maintenance

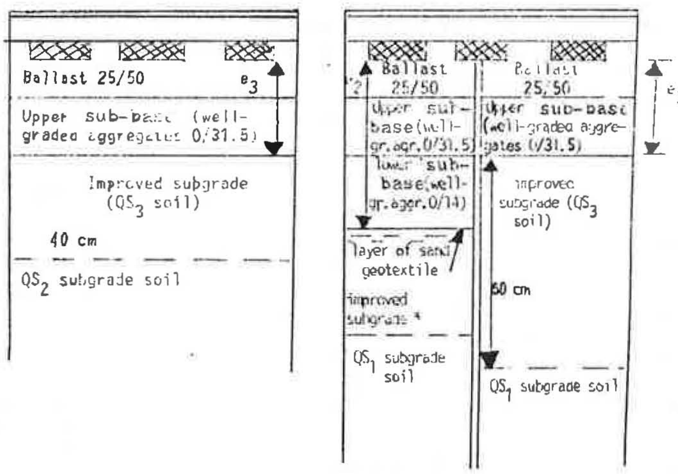
After a track is renovated, the cost of maintaining its level is not constant ; it steadily increases. Moreover this cost depends to a considerable extent on the quality of the foundation ; this well-know fact is evidenced by the difference in the number of maintenance operations between sections of track of the same age (and the same type of superstructure) carrying equivalent traffic.

For a given category of traffic on a given railway system, it is possible to evaluate statistically the average annual number I_m of levelling operations in function of the age N of the track. We obtain a curve of mean evolution (fig.6) : $I_m = f(N)$.

4a. Conventional structures (improved subgrade of the same nature as the subgrade soil).



4 b: Structures incorporating a built-up improved subgrade (of better quality than the subgrade soil), or treated with hydraulic binders.



* Consisting of:
. treated soil, thickness 30 cm.
. QS_2 soil, thickness 55 cm.
. QS_3 soil, thickness 40 cm.

4 c: Structures incorporating a geomembrane

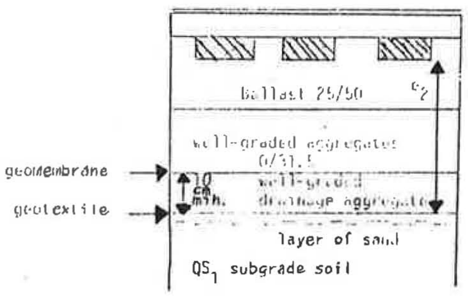


Fig. 4. Standard base course structres (the values of the thicknesses e_1 to e_3 are specified in fig. 3)

on a particular section of track, the number of operations I for a given age N may differ by the average value I_m. In this respect it is convenient (fig. 6) to define a factor k, called the coefficient of bed maintenance, such that $k = \frac{I}{I_m} = \frac{AC}{AB}$.

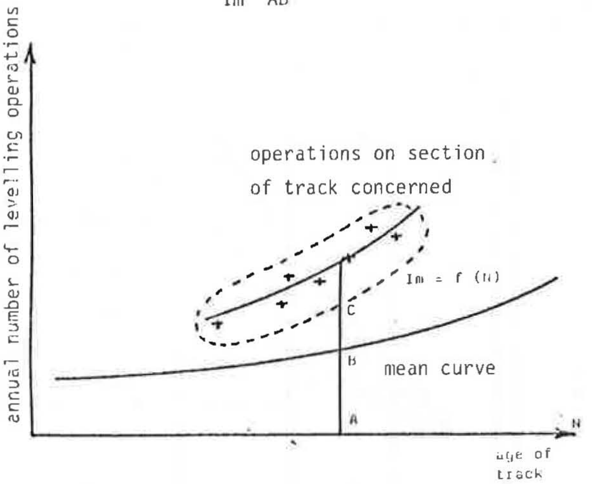


fig 6. Coefficient of bed maintenance k. $\left(k = \frac{AC}{AB}\right)$

By definition, k = 1 in the average case, but may reach a value of 5 (and even more) in the case of a very poor foundation.
Semi-theoretical, semi-empirical studies have made it possible to link the value of k with the dynamic stress exerted on the subgrade (depending on the grade of soil QS_1) and with the traffic carried by the track in question (1), (5), (6).
For new tracks, it has thus been possible to establish the structural design of base courses shown in fig. 3. This structural design is such that the predictable value of k is 0,5 (or exceptionally 1 when the reduction factor c is applied).
For existing tracks, the influence of a modification in the thickness of base course on the value of k has been established in the form of charts (fig. 7).

7.2. "Duration of tampability" of the ballast

Pollution of the ballast (10) can have many causes :

- Self-attrition : in this respect the hardness of the ballast (7) is expressed in the form of a coefficient DR established on the basis of the Los Angeles coefficient LA and the wet Deval coefficient DH, using the chart shown in fig. 8.
- The rise of fines from the subgrade and the base courses ; this phenomenon is linked with the quality of the base courses, and hence with the coefficient of maintenance k.
- Pollution from the environnement.

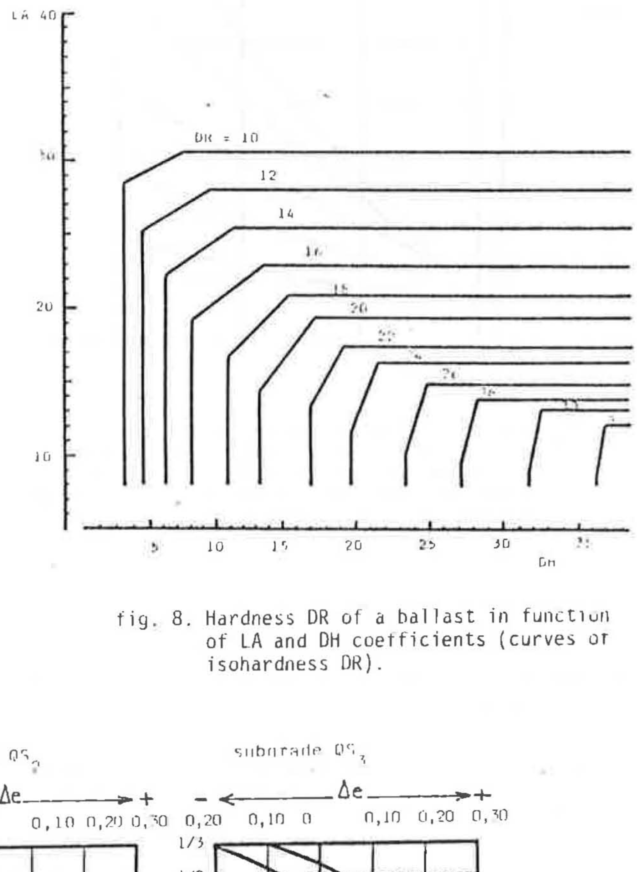
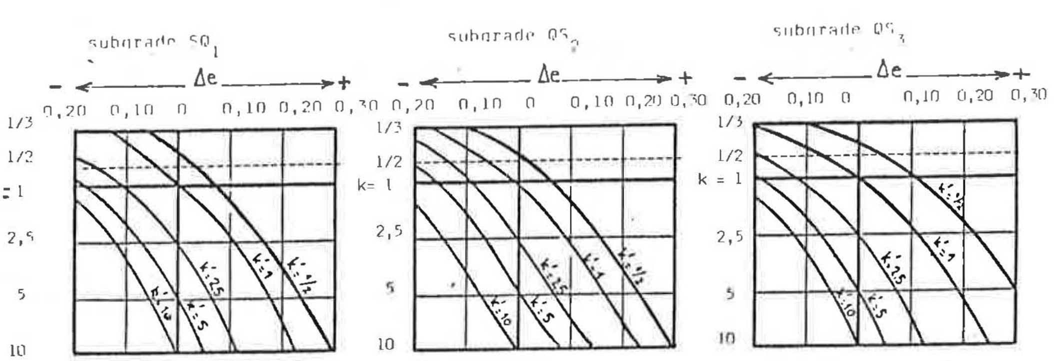


fig. 8. Hardness DR of a ballast in function of LA and DH coefficients (curves of isohardness DR).



k = existing coefficient of maintenance
K' = future coefficient of maintenance
Δe = modification of thickness of base courses in metres

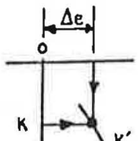


fig. 7 Influence of a modification Δe of the thickness of the base course (in the case of tracks of IUR Groups 1 & 2).

This problem assumes greater importance on new tracks, whose level is maintened by mechanical tamping (9). When the degree of pullution (the ratio of fine solid pollutant elements to the total solid mass) of the ballast attains 12.5 % the whole layer up to level of the sleepers is clogged, and tamping becomes ineffective

A recent study (10) has made it possible to link the "duration of tampability" of the ballast with the coefficient of maintenance of the base course k and the hardness of the ballast DR, in the form of charts, an example of which is shown in fig. 9.

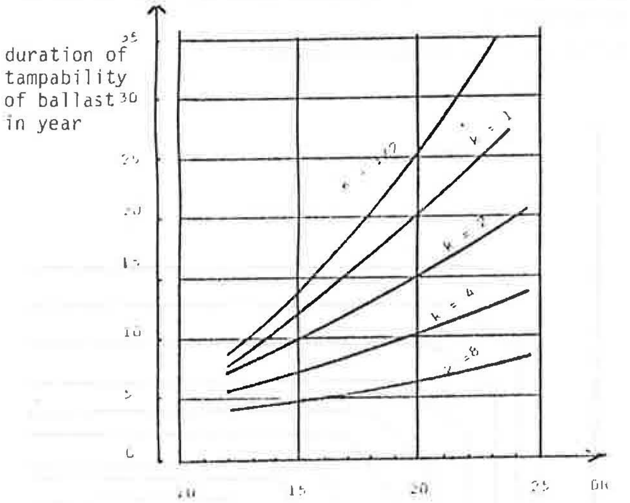


fig. 9. Duration of tampability of the ballast in function of the coefficient of maintenance k and the hardness of the ballast DR (track carrying 85,000 tonnes a day and located in an envorinment creating only slight pollution).

7.3. Improvement of quality resulting from the use of a geotextile.

The foregoing considerations enable us to make a comparative evaluation of the techniques outlined in figures 4a and 4b in the case of a poor soil of grades QS_1 :

- Conventional structure of thickness e_1 incorporating a geotextile.
- Structure incorporating a "built-up" improved subgrade.

When the work is carried out in dry weather and under favourable hydrogeological conditions, the perfect geometry of the courses is conformed to in both types of structure, and in both cases one may count on obtaining a value of k = 0,5.

The duration of tampability is then 18 years, according to fig. 9 assuming a traffic of 85,000 tonnes a day and an only slightly polluting environment, and a ballast hardness of 17. The last-named value is required in the case of tracks carrying traffic at conventional speed ($V \leqslant 200$ km/h).

When the weather or hydrogeomogical conditions are less farourable, the interface geometries are less well conformed to (rutting), so that at certain points the strucuture is under-designed. In this respect the presence of a geotextile means that the conventional structure is less adversely affected.

Thus one may consider that (using the QS_1 chart fig. 7) the value of k will rise to 1 in the case of the structure incorporating a geotextile (underdesigned by about 0.07 m), and to 2 in the case of a structure incorporating a built-up improved subgrade (underdesigned by about 0.15 m).

This affects the respective durations of tampability of the ballast, which fall to 15 years in the geotextile case and 12 years in the built-up improved subgrade case. This comparison is shown in fig. 9b.

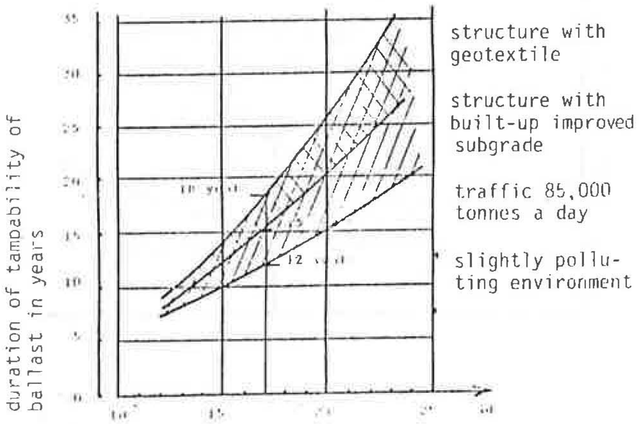


fig. 9b. Comparative durations of tampability of a structure incorporating a geotextile and a a structure incorporating a built-up improved subgrade

VIII. CONCLUSIONS

The use of structural additives in base courses resting on poor subgrades and in drainage systems greatly facilitates the work of laying. The structures built under these conditions have a better technical quality :

- Conformity to the declivities of the course interfaces.
- Better compaction of courses, despite the deformability of the subgrade.
- Better hydraulic functioning of the whole.

When the track is in service, this is reflected in a lower cost of maintaining the level and in an increased duration of tampability of the ballast.

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