THE STABILIZATION OF RAILROAD EMBANKMENTS NEAR GOUDA

Ir. J.L.A. CUPERUS

1. INTRODUCTION

General. The railroad section Gouda-Oudewater is situated in the western part of the Netherlands and constitutes part of the main line Utrecht-Rotterdam (figure 1).

The section Gouda-Oudewater, the same as the Gouda-Rotterdam section belongs to those parts of the Netherlands railway system which rest on the poorest soil.

The roadbed was constructed around 1855 by casting up soil, obtained from the parallel ditches and from borrow pits which were dug in the neighbourhood of the railroad.

The upkeep of this section, that is to say the relevelling of the profile by periodical raising, was done originally with ballast sand, but from about 1900 onwards with ballast gravel beneath and between the tracks.

Hereby a body of sand and gravel has been created in course of time, the thickness of which varies from 1 to 5 metres and resting on more or less consolidated layers of subsoil consisting of peat and soft clay. (figure 2)

An incident of consequence for the history of the railroads on soft subsoil in the Netherlands was the serious roadbed sinking which took place at one point of the railway Gouda-Rotterdam about 18 years ago (figure 3).

Probably the periodic revelling of the profile of the roadbed by means of gravel and sand, as also the regular recurrence of mobile loads, must have caused the important disturbance of the equilibrium on January 11th 1930, when one half of the double-track railroad suddenly gave way over a length of about 50 metres and to some 3 metres below the original level. The sinking of the embankment caused the heaving up of peatsoil in the parallel ditch.

As a consequence of this incident the vigilance of the inspections was redoubled on those other railway sections of which it was known that they were built on soft subsoil.

These inspections concerned not only the settlements, but also the phenomenon of the so-called undulation of the roadbed.

In principle the latter phenomenon consists of a slight resilient sagging of the entire body of the formation when a mobile load is passing. The sagging, being of a resilient nature, is restored after the load has passed, so that the roadbed returns to its original level. When the load is passing quickly, the downward and upward movements of the roadbed, even if they are slight, may be clearly observed by the eye and give the impression of undulation.

In respect of settlement and undulation the section Gouda-Oudewater showed a very unfavourable condition. As a consequence it was not even possible to obtain a reasonably settled longitudinal profile of the track in spite of much expensive upkeep.

Besides, the gradings in this section revealed that at some points the annual soil settlements were 3 to 10 cm.

These facts gave rise to an extensive investigation at km 29.400 and at km 29.180 of this section, about 3 km east of Gouda, which took place in 1937.

Several data were compiled.

1. The annual setting of the roadbed was investigated:

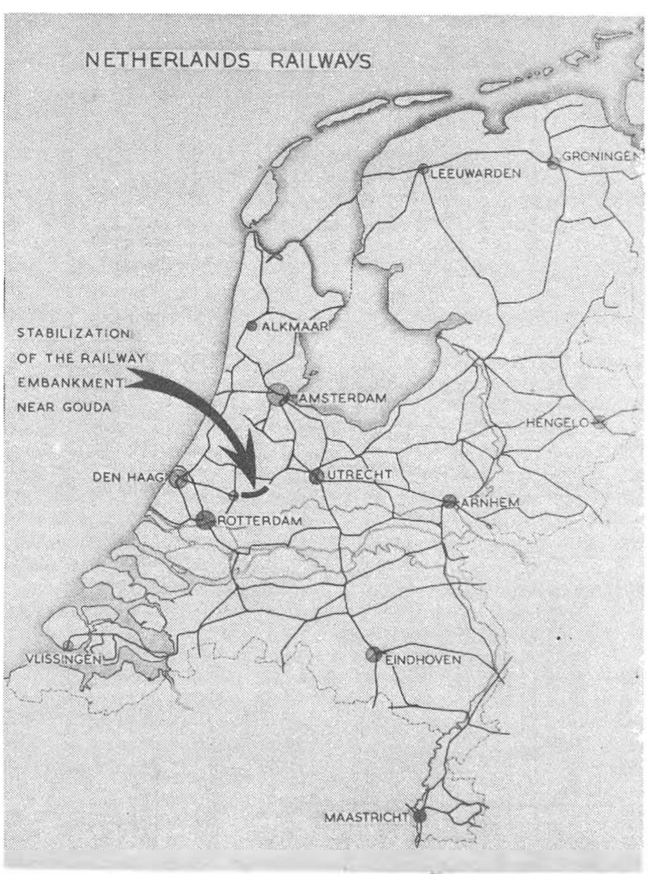
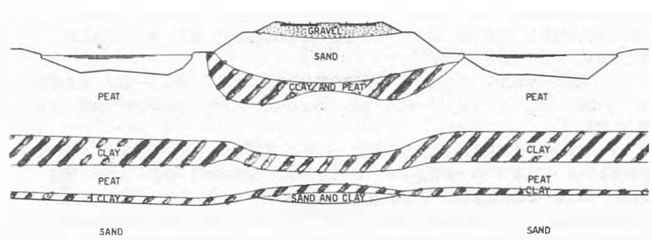


FIG. 1



CROSS-SECTION km 28etc

FIG. 2

CROSS-SECTION km 38 750

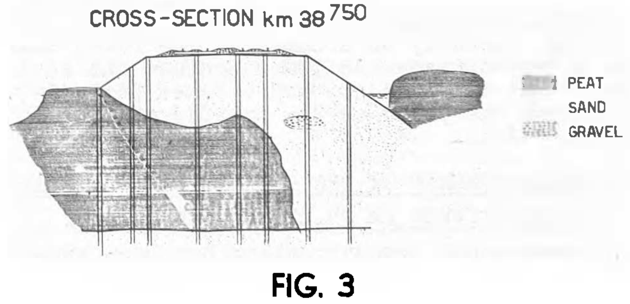


FIG. 3

a) from history since the construction,
b) from gradings during the last years before 1937,
c) from statements by the Engineers of the Permanent Way regarding the gravel-ballast- and sand-material applied in the last years before 1937.

From the data obtained it could be ascertained that at the point concerned excessive annual settings occurred considerably deviating from the annual averages since the construction. Moreover the periodical upkeep had not succeeded in maintaining the longitudinal profile at its original level. In 1937 the raillevel was about 60 cm lower than immediately after construction in 1855.

2. A number of borings were executed with the screw-auger as well as a number of sounding tests with the apparatus of Barentsen, in order to get as complete as survey as possible of the soil-conditions under and alongside the railroad. (figure 4)
3. Data were compiled concerning the observed undulation. The undulation of the roadbed was measured when trains were passing at different speeds with the aid of an apparatus constructed for the purpose and which is described in the publication IVa 2 by Ir. F.C. de Nie. The measurings were taken on both the incoming and outgoing tracks. The relative position of the points of measurement with regard to the tracks and results of the measurings are shown and given in the figure 5.
In the graphs the velocities of the trains have been indicated along the abscis and the corresponding roadbed movements along the ordinate.
The observations have taught us the following: With Diesel-Electric trains the downward movement remains constant at train speeds varying from 0 to 60 km/h inclusive, whereas above the latter speed, said movement increases with the speed and moreover an upward movement above the zeroline becomes visible, which also increases with the increase of the speed.

The fact is, that for trainspeeds above 60 km/h a phenomenon of resonance in the elastic movement becomes manifest and the maximum amplitudes for the downward and resilient movements have not been reached at a train speed of 120 km/h.

At this speed a movement of 9.3 mm down + 3 mm up = 12.3 mm in total was observed at point C.

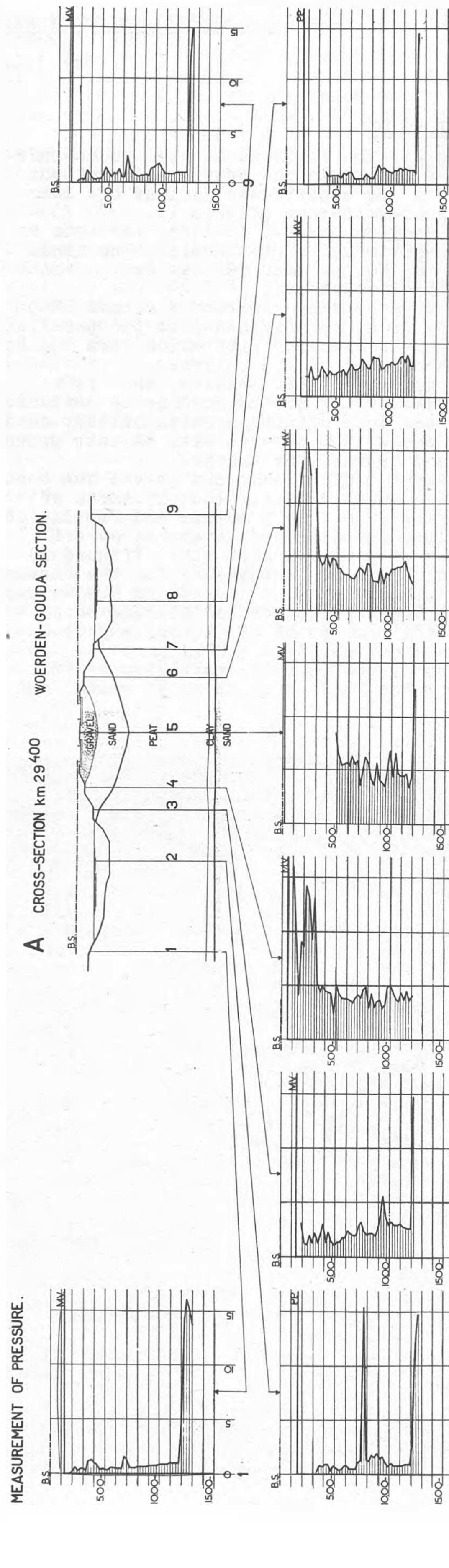
The experimental runs with a steam locomotive gave a value only downward of 9.5 mm for the smaller speeds of from 5 to 30 km/h, whereas for speeds of 45 km/h and up a constant value of about 8 mm was measured.

The remarkable difference between both graphs results from the important difference in the nature of the load-system of the two kinds of traction.

The influence of the mobile load reaches a maximum at the points at the outside of the roadbed, gets slightly less in the axis of the railway, probably on account of the fact, that the affected track-bed leans against the sand bed of the other track, and becomes insignificant at the point at the outside of the unused track.

II. REINFORCEMENT OF THE RAILWAY-SECTION NEAR GOUDA BETWEEN KM 29.075 and KM 29.880.

Once these investigations had been completed a design was made up for the reinforce-



THE DATA OF THE MEASUREMENT OF PRESSURE GIVE THE PENETRATION LOAD WHEN SOUNDING WITH THE BARENTSEN DIVICE IN kg/cm²

FIG. 4

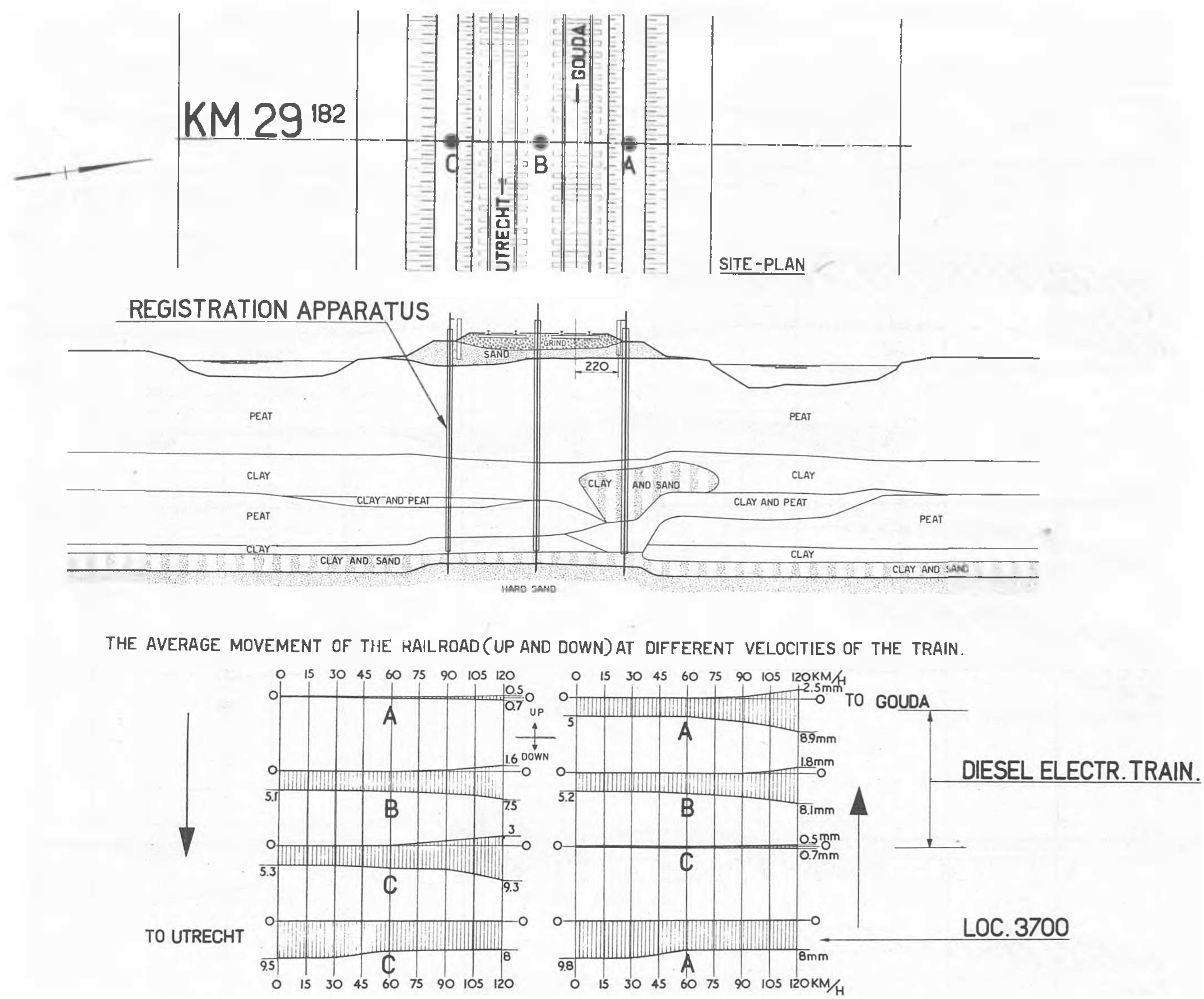


FIG. 5

ment of the entire railroadsection between Gouda and Oudewater.

The periodic gradings of the longitudinal profile clearly showed that, as regards the settings of the subsoil, there were several bad places in this section and that the part between km 29.350 and 29.800 was in an exceptionally bad condition (during 10 months in 1936 the picket at 29.400 lowered 11 cm). Moreover the roadbed between 29.075 and 29,350 showed remarkably intense movements of the road bed when trains were passing.

Before proceeding to the reinforcement of the entire railwaysection, it was decided to start off with special measures for this exceptionally bad stretch near Gouda and to reinforce about 800 metres of the railway embankment. (figure 6)

In the first place a reinforcement of the roadbed was considered by dumping sand on both sides. (figure 7)

1. Filling in the parallel ditches along the railway with sand at a slow rate in order to prevent a disturbance of the equilibrium of the subsoil. When executing this method, it is advisable to apply the load in such a way that the increase of the waterpressure in the subsoil be kept limited and does not exceed a certain maximum. This can be obtained by applying the filling in with sand by way of layers at not too quick a rate.
2. Filling in with sand as planned under 1, but this time on a pre-fabricated bed of fascine-work.

The principle underlying this method is exactly the same as mentioned under firstly. The bed of fascines merely serves the purpose of a better distribution of the pressure on the soil which - as is well-known - may not be considered as a homogeneous substance.

3. Dumping the sand at a fast rate, with the idea of penetrating the subsoil as deeply as possible with sand. This method is based on a different principle.

The first and second methods both have in view a breadthwise extension of the existing roadbed whilst retaining the equilibrium of the entire area; the third method, while of course, also envisaging the retention of the equilibrium of the existing roadbed, aims at replacing the soft strata at both sides of that body by sand and at the consequent enclosing of the soil strata supporting the roadbed. The penetration with sand is attended with a disturbance of

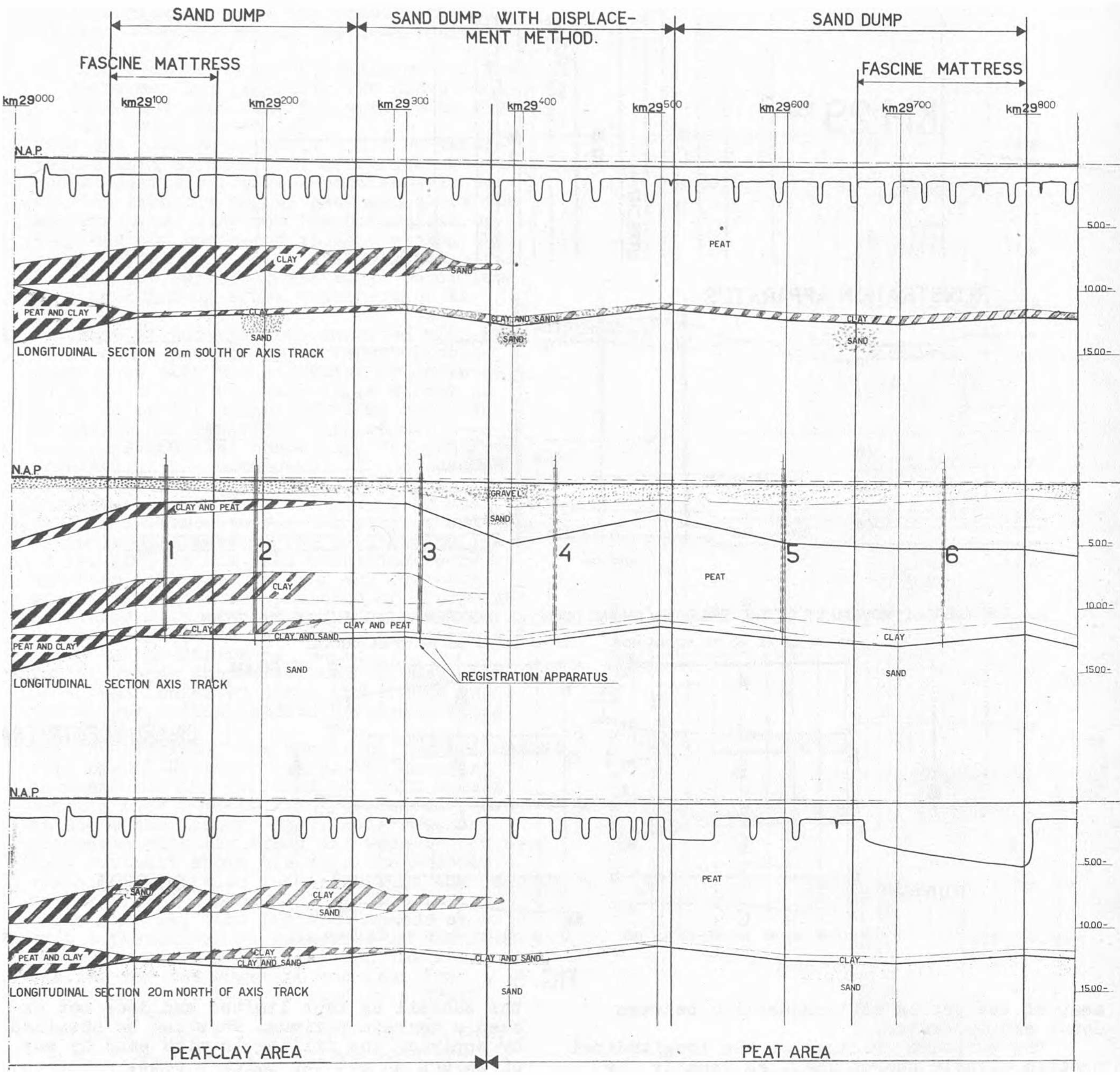


FIG. 6

the equilibrium.
Such a disturbance may arise very suddenly and may be very extensive; the inherent forces and mass-action may become considerable and the immediate surroundings are in danger of being involved. Hence this method entails more risk during the execution than the two first-mentioned ones.

Moreover the possibility was considered to improve the situation by the execution of other constructions, for instance by making a slab of reinforced concrete on pile-foundation, on which to support the ballast-way with the tracks.

This plan, however, was handoned, as also the application of coffer-dams as executed along the railway Gouda-Rotterdam in 1930, on account of the heavy expenses involved.

It was finally decided upon to execute the three alternative methods of sandfilling mentioned above by way of experiments.
The execution took place as follows:
Before filling in the existing railway ditches with sand, new ditches were dug at a distance of about 20 metres from the existing ones. This distance was chosen in such a manner that no digging took place in the active region of the supposedly most unfavourable shearing plane.

Project no. 1 (figure 8).

The sand which was hauled by train, was unloaded along the slopes of the stretch of road that was to be reinforced and dumped at the work by means of wheelbarrows directly after unloading.

During the refill periodical readings were taken with previously installed waterpressure-metres and the dumping of sand was continued until the meters showed a certain maximum, after which the execution was temporarily stopped

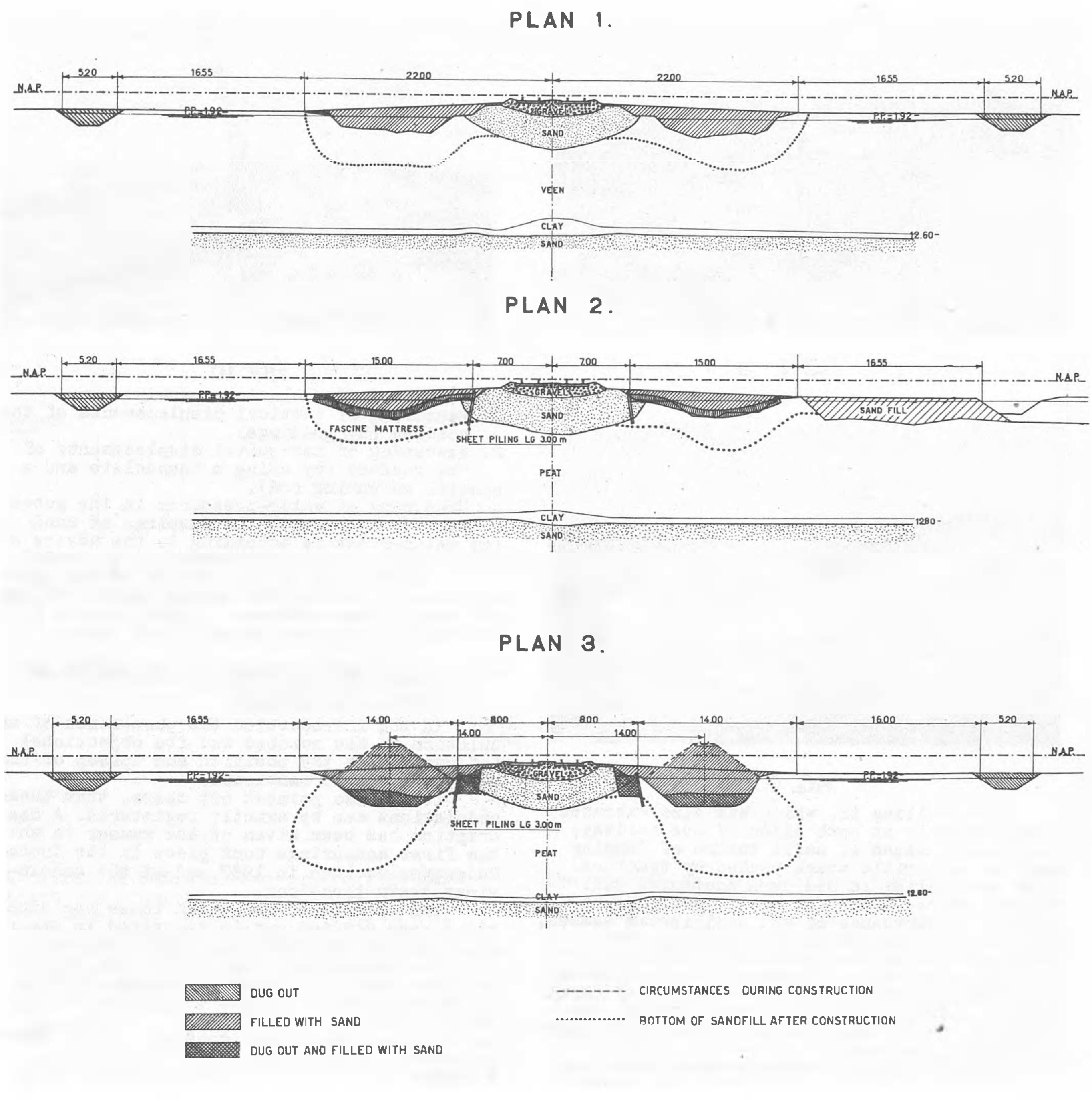


FIG. 7

As a result of the load of the sand the pore water became overstressed and was forced out of the layers of peat and clay, whereby the overpressure decreased, although at a slow rate.

Once the pressure of the water had decreased sufficiently, the sand that had sagged in the meantime was replenished once more, whereby in turn the meters showed higher readings again, etc. etc.

Thus a gradual consolidation of the subsoil took place and a disturbance of the equilibrium was prevented.

Project no. 2.

In principle the execution is the same as that of the first project and will not be discussed for lack of time.

Project no. 3.

In this project the penetration of sand into the soil beneath the parallel railway ditches was aimed at, and it was attempted to make the disturbance of the equilibrium as gradual as possible by dredging these railway ditches beforehand down to a level of 2.50 metres below the groundwater level of the polder (a polder is a tract of reclaimed land).

Two draglines did the dredging simultaneously at both sides of the railway and in the same cross-section.

As the existing condition of equilibrium of the railway was changed by this dredging, the deepening of the ditches resulting from it was immediately followed up by the filling in with sand.

FIG. 8

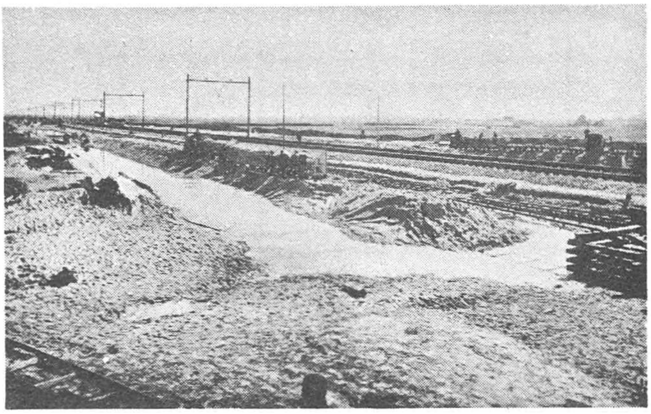


FIG. 9

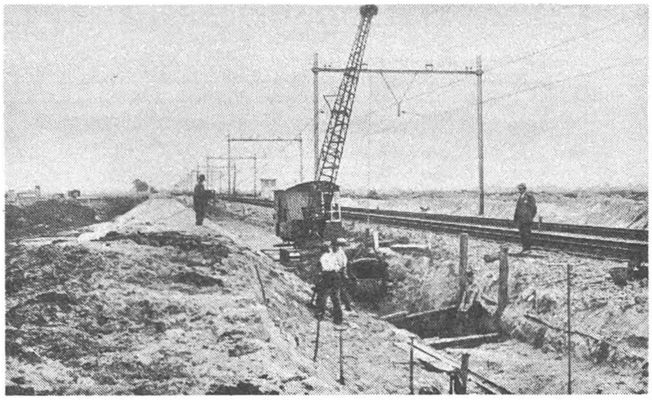


FIG. 10

This filling in, which was also executed simultaneously at both sides of the railway, was done by means of small trains of dumping cars on decauville track pushed by tractors. When the filling in had been continued till about 2 metres above the water level of the polder a disturbance of the equilibrium ensued, considerable quantities of adjoining peat being heaved up. The penetration took place at both sides and simultaneously except in one place where there was a rather deep pool north of the railway. Here the sinking of the sand occurred already when the ditch was about halfway filled with sand.

A special precaution was taken with this third method by previously driving in sheet piling of about 3 metres length along the slope of the ditch at the railroad side.

The dumping of sand was continued until it reached about 2 metres above top of rail of the existing railroad and remained at this level for about 3 months.

There upon a trench was dug by dragline between the sheet piling and the roadbedbody to a depth of about 2 metres and immediately closed up with sand taken from the surplus height of the dams which was tamped in layers. (fig. 10)

In this manner the existing roadbed was united with the dumped sand dams.

The supply of sand for the complete job took place by train.

A great number of measurings were taken during the execution of the work, in order to continually check up the conduct of the existing roadbed and moreover to get a better insight into soil mechanics, namely:

1. Measuring of vertical displacements of the roadbed (by gradings).
2. Measuring of horizontal displacements of the roadbed (by using a theodolite and a special measuring rod).
3. Measuring of water-pressures in the subsoil beneath and beside the dumpings of sand (by water-pressure according to the advice of the Laboratory for Soil Mechanics at Delft).

A discussion of the results of the measurements has to be omitted herein because of want of time. I must refer to my publications in De Ingenieur numbers 26 and 27 of 1947.

III. UNDULATION PHENOMENA OF THE ROADED AND METHOD OF COMBATING.

In the introduction the phenomenon of undulation of the roadbed and its objectional influence upon the position and upkeep of the permanent way is mentioned.

It is also pointed out there, that these undulations can be exactly registered. A description has been given of the manner in which the first measurings took place in the Gouda-Oudewater section in 1937 and of the conclusions drawn therefrom.

The apparatus with which these registrations were carried out is described in paper IVa 2 of the Proceedings of this Congres.

The measurings were carried out in September when trial trains were passing, namely:

1. Diesel Electric trains consisting of 2 three-carsets, speed 120 km/h.
2. Electric trains also consisting of 2 three-carsets (120 km/h).
3. Steam trains of the normal service (90 km/h).

The results of these measurings have been recorded in figure 11.

Apart from the downward movement during the passing of the trainload an upward movement has also occurred in the intervals between the loads of the cartrucks reaching above the original level of the roadbed (Zero-line).

An important difference may be observed between the behaviour of the roadbed when Diesel- and Electric trains are passing, in comparison with the passage of steam trains.

With the Diesel- and Electric trains a regular downward and upward movement of the roadbed takes plane, whereas with steam locomotive load a continuous sagging occurs under the influence of the complete set of axles. The carriages behind the steam locomotive, however, give rise to the normal undulation phenomena, though to a smaller degree.

The graph clearly shows the influence of

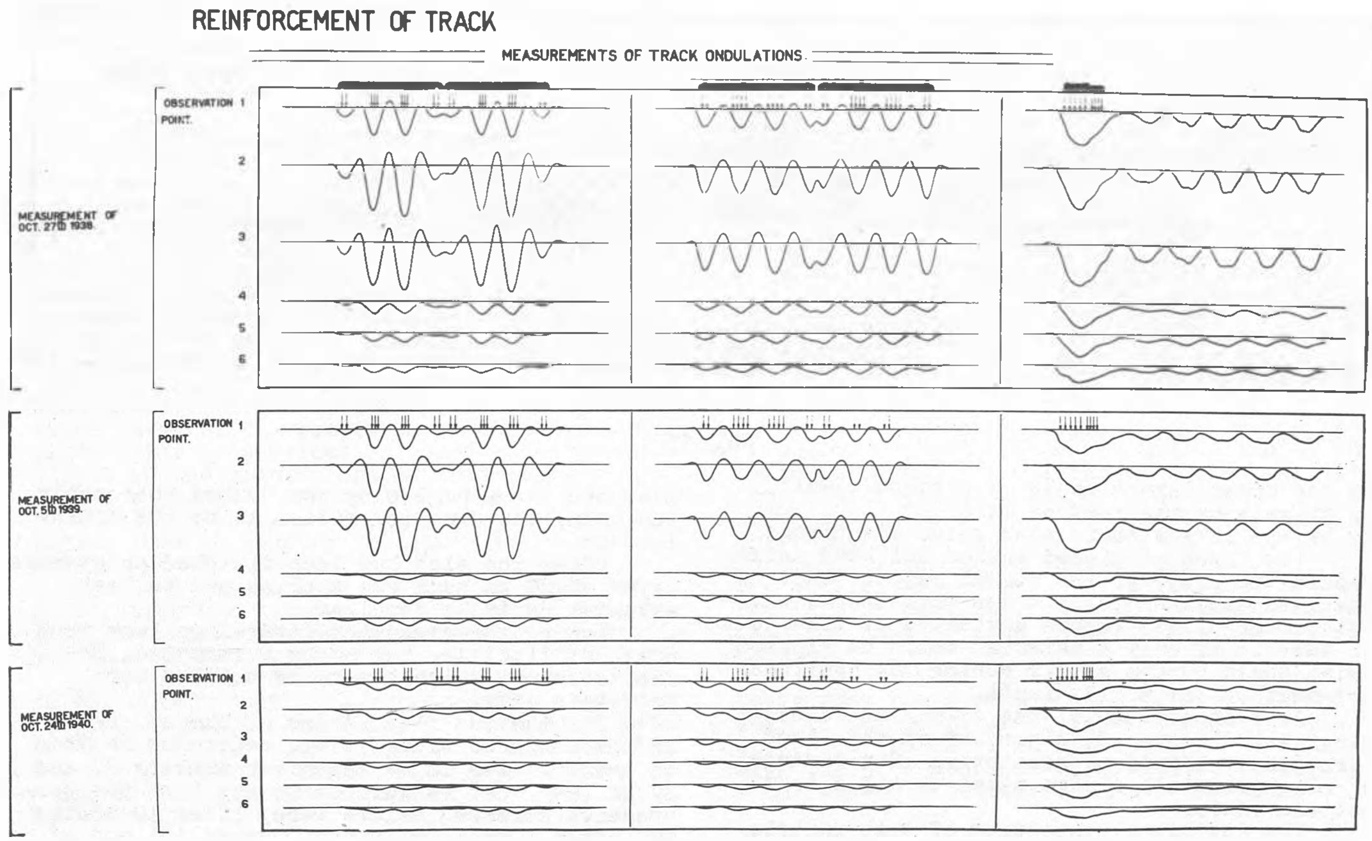


FIG. 11

the distances between load centers, in which respect the locomotive affects the roadbed more favourable, whereas the 3-axle Diesel trucks give the most unfabourable results. The movements which occurred with the lastmentioned trein-sets at a speed of 120 km/h reached a maximum at measuring-point no. 2, where a total of 12 (down) + 3 (up) = 15 mm in total was recorded.

A slight improvement was expected from the reinforcement work,due to the lateral dumpings of sand.

After this reinforcement had been executed experimental runs were carried out once more in October 1939 in exactly the same way as had been done in 1938 at the 6 points of the railroad.

The results of these measuring are also given in figure 11.

When compared with the results of 1938, an improvement was indead apparent.

Though in general the percentage of the improvement was beyond expertation, still an as yet remaining total movement at measuring point 2 of 12.1 mm at the passage of Diesel trains and of 6.8 mm when Electric trains were passing, was considered far too high for a daily operation, at 120 km/h velocity.

Therfore there was more than sufficient reason to keep on the lookout for means to combat the phenomenon of undulation.

In order to get a better insight into the problem an investigation was set up once more of the manner in which the undulation was transmitted in the subsoil.

The result of this investigation is given in figure 3 page 10 volume II of the Proceedings of this Congress.

On the lefthand side of the figure a survey is given of the local soil layers; at the side are the values of the soundings according to Barentsen corresponding to said layers.

Moreover the graphs of undulation are shown, taken at different depths, special attention being paid to the layer situated immediately under the sand bed of the road.

With all kinds of traction a gradual decrease of the movement with increased depth can be observed.

Furthermore the graphs of undulation were remodelled into simple curves at the extreme right, the maximum value of each record being set out horizontally.

Broadly the observations show that the load stretches over a continually larger area the more the depth increases. It is, however, remarkable that the layer of peat between 4 and 7 m below N.A.P. (New Amsterdam Level) forms an exception to this rule.

All this confirmed the hypothesis that the undulatioh might be effectively combated by improving the pressure distribution of the mobile loads in the upper layers of the subsoil.

The improvement of the pressure distribution

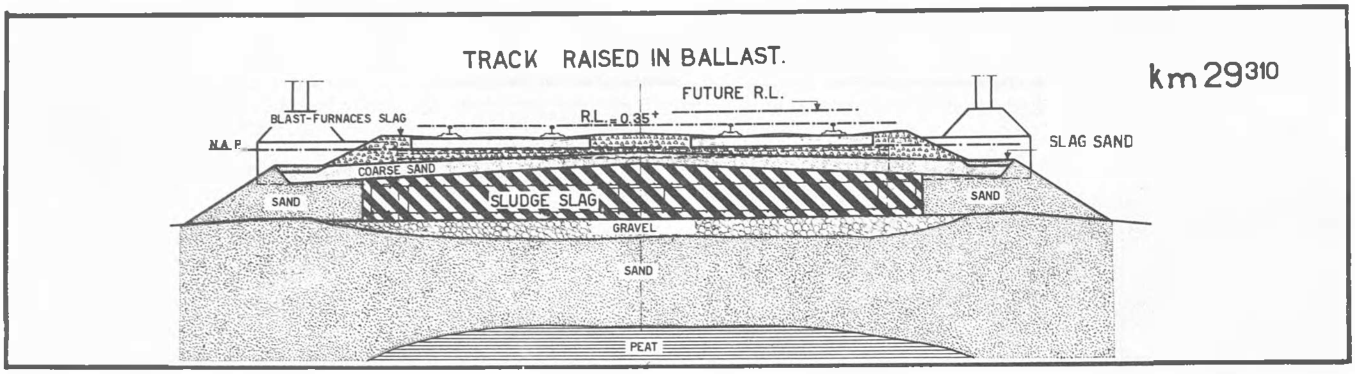


FIG. 12

in the upper layers could be brought about:
1. by raising the roadbed itself;
2. by applying a rigid slab under the tracks.

The first mentioned method had been intended in the project. The second method could be executed simultaneously under both tracks without either of the tracks having to be taken out of service if only a material could be applied which would harden slowly during the continual movement by the mobile loads.

As such a material the so-called "sludge slag" was discovered, a product of the Blast Furnaces at IJmuiden, consisting of a mixture of slag-granulate sludge mixed in mills in a certain ratio.

The following properties of this material gave rise to its choice for this work:
1. the thickening only begins to be noticeable after some days;
2. the hardening takes place very slowly lasting for some years;
3. the material has a low specific gravity.

The first property enables the material to be mixed in the factory, loaded in railway vans, transported and finally to be worked up under the tracks.

The second property is the determinant factor, as the material has to set after it has been worked into a slab, while it is being kept in continual motion by the passing trains.

The third property is of importance in connection with the soft subsoil. Any possible reduction of weight is a requisite of utmost importance in this case. The hardened material in moist condition weight 2 tons per cubic metre.

The excessive undulation of the roadbed occurred over a length of 300 running metres. Before starting the construction of a slab of sludge-slag of this length, a trial-piece was made of a length of 25 running metres.

Taken as a whole, the experiences with this trialslab were not unfavourable and gave rise to the design according to figure 12.

In this design the slab has a width of 8 metres, and thicknesses of 80 cm in the middle and of 60 cm at the sides. Upper and lower reinforcements of longitudinal and transverse steel roads are applied. Beside and between the tracks there are longitudinal reinforcements connected by vertical stirrups.

The sludge slag was carried from the Blast Furnaces at IJmuiden in waggons and unloaded and put into work during daytime in between trains. The trakcs were lifted simultaneously and gradually raised. Between and beside the sleepers the sludge slag was tamped thoroughly and under the sleepers ridden in by the trainloads.

After the slab had been finished an average layer of 20 cm sand was applied and ballast material could be supplied.

During the execution several railway technical difficulties had to be surmounted, the discussion of which has to be omitted for brevity's sake.

For the compiled values of the strengths of the hardened sludge slag, reference is made to the articles in De Ingenieur numbers 26 and 27 of 1947. Let it suffice to say that the compressive strength values were: after 10 months 65, after 1 year 75, after 2 years 135 and after 3 years 160 kg/cm^2, whilst the tensile bending strength values were 20, 22, 27 and 30 kg/cm^2 respectively.

Ten months after construction of the slab the hardening process was supposed to be sufficiently advanced to allow trial runs to be undertaken for the third time.

These trial runs took place in October 1940 and during which recordings were made at the same 6 points as in 1938 and 1939, gave a very satisfactory results (figure 11)

The improvement in the undulation of the roadbed at point 2 as a result of the measures taken was about 90% of the initial movement, namely: 2.3 - 0.7 = 1.6 mm.

As a matter of fact only the total resultant amplitude is of importance; consequently, if the upward resilience at a certain point remains below the Zero-line before the next load reached the point, the into account in negative sense.

IV CONTINUATION OF THE WORK

The expenses incurred by the three projects differ considerably. It goes without saying that project No. 1 dealing with the slow filling in, is cheapest.

Premising that the three methods should lead to the same end, the choice for further reinforcement work would not be difficult. However, when capitalising the roughly estimated yearly upkeep expenses of the 3 projects it cannot be stated at first hand that project no. 1, although more attractive in construction, should be per se the most desirable solution, as practice has shown that it involves very much upkeep both now and in a distant future. The continual setting of the roadbed, especially at the sides, precludes a properly settled profile of the road. The same construction, however, may well result in a better condition of the roadbed by the additional application of a slab of sludge slag.

After due consideration of the advantages and disadvantages of the different methods, it was decided to apply either the first, second on third method dependent upon the condition of the soil and to apply a slab of sludge slag where necessary.

The stabilization-work was continued in 1940, starting from the station Oudewater.

Along the first 200 running metres of the railway a bed of fascines was considered necessary on account of the presence of adjacent premises. Thereupon a trial was made to reinforce another very bad stretch of the railway by making use of the method of penetration, but this resulted to be unfeasible; even when the sandfillings were raised to 3.50 m above the water level of the polder no penetration took place (vide my publication under sub-section IIIb 1 of the proceedings of this congress).

A compromise was decided upon, whereby the parallel ditches were dredged first and then filled in with sand up to 1.50 m above water-level.

Only at one single point of the railway penetration has taken place, but apart from that, the work has been executed satisfactorily and is nearing completion.

In the resident centre of the town of Gouda the reinforcement is being executed according to project No. 1, and this at a very slow rate, whereby not only the customary measurings of the water pressure are taken, but also some other instruments are installed in order, to observe lateral soil displacements (see my publication in the proceedings Sub-Section IVa 1.)

Finally, a slab of sludge slag will still have to be applied along a large part of the section under review in order to ensure a settled profile of the railway, not only in those parts where undulation of the roadbed takes place but also in other stretches, where local irregular settings of the roadbed occur continually.

<u>CONCLUSION</u>:

1. Reinforcement of a railway on a soft subsoil must take place: in behalf on the <u>safety of the railway transport</u>, when the setting of the railway has acquired such proportions that the necessary periodical restoration of the profile of the railway will lead to disturbances of the equilibrium of the subsoil;
2. in behalf of <u>maintaining or increasing the speeds of trains</u>, when the undulation of the railroad during the passing of trains has acquired such proportions, or else the soil-setting are unequal to such anextent degree that a sufficiently settled condition of the tracks at the required speed is not ensured.

The reinforcement in behalf of safety, preventing the loss of equilibrium of the roadbed, may take place by dumping sand into the ditches beside the railway.

The reinforcement in behalf of maintaining or increasing the speeds of trains may take place during the operation of the railway by applying under the tracks, a reinforced slab of "sludge slag" or of a material with similar properties with regard to setting time and elasticity.

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<u>THE CONSTRUCTION OF THE MAASTUNNEL AT ROTTERDAM</u>

Ir. J.P. van BRUGGEN

When in the harbour district of Rotterdam a second connexion of great capacity was needed between both banks of the Maas River a choice was to be made between a tunnel and a bridge. As the river traffic was very dense and consisted of ocean-going ships a fixed high level bridge was the only possibility for an overground connexion. This solution however had the disadvantage of long ramps that made the average distance to be travelled by motorized traffic considerably greater than for a tunnel. As there was no appreciable difference between the cost of construction plus capitalized maintenance of both types, the tunnel was chosen. (fig. 1)

The Maas tunnel consists of two passages, each for two lines of traffic and, for the river part, of an additional passage for pedestrians and cyclists. This latter passage is divided into an upper part for the cyclists and a lower part for the pedestrians (fig. 2). It is connected with both river banks by means of escalators.

The river part of this tunnel was executed by the so-called trench method, whereby 9 rectangular tunnel units of reinforced concrete having a length of approximately 63 metres, a width of approximately 25 metres and a height of approximately 8,5 metres, were floated into position and sunk into a dredged trench, after which they were connected and covered.

The section executed by the trench method, terminates on both river banks in ventilation buildings, founded on pneumatic caissons. Each of these two ventilation buildings houses 16 fans of the propeller type for the automobile tunnels and one centrifugal fan for the pedestrians and cyclists tunnel. The foundations of these buildings contain the lower ends of the escalators, which terminate at their upper ends in separate entrance buildings (fig. 3).

The ventilation buildings are situated at about the quarter points of the total length of the covered tunnel. These points were favourable for a variety of reasons. In the first place the lengths of the four ventilation sections into which each passage is divided became almost equal, and consequently the consumption of energy for ventilation was the lowest possible. Secondly, these buildings, when