VI a 6

SETTLEMENT RECORDS ON BRIDGES FOUNDED ON SAND

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When constructions are founded on clay-layers, the settlements of these constructions can be computed from the results of consolidation tests performed in the laboratory on undisturbed samples. On the contrary, when the foundation soil is a thick sand layer, the calculation of the settlements generally is omitted for a double reason:

1) it is very difficult and/or expensive to take undisturbed samples in sand layers underneath the groundwater table and much more difficult to transport them without shocks or vibrations.
2) sand, at least when of medium or high compacity, is a less compressible material than a clay, even when of high consistency; thus the settlements of buildings founded on sand will usually be much smaller than those of constructions founded on clay.

From the results of the sounding tests it is possible to get sufficiently precise data about the degree of compacity of the sand. Moreover for the case of sands of medium or high compacity it is possible to deduct from these tests a lower limit for the constant of compressibility. With the values so obtained it is possible to compute an upper limit for the settlements.

Such computations seem to be interesting for heavy hyperstatic constructions, as bridges in reinforced concrete consisting of continuous beams resting on many supports.

To control the settlements computed from the sounding tests, the settlements of a certain number of bridges were regularly measured from the starting of the construction works.

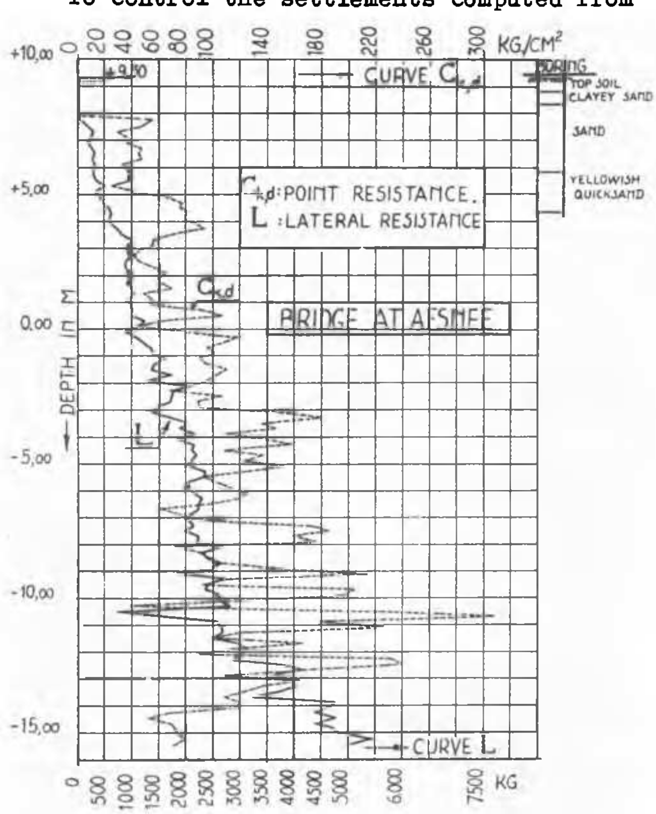
Here after for the first of the bridges the method for the computation of the settlements is given, and the method followed for the measurements described. For the other bridges only the results of computations and measurements are generally given.

BRIDGE OVER THE MOTORROAD BRUSSELS-OSTEND AT AFSNEE.

This is a bridge in reinforced concrete consisting of continuous beams on 4 supports. The results of a deep sounding test and of an ordinary boring are given in fig. 1. It is seen that from 1,50 m depth underneath the soil surface the resistance is relatively high and that the soil has a definite sandy composition.

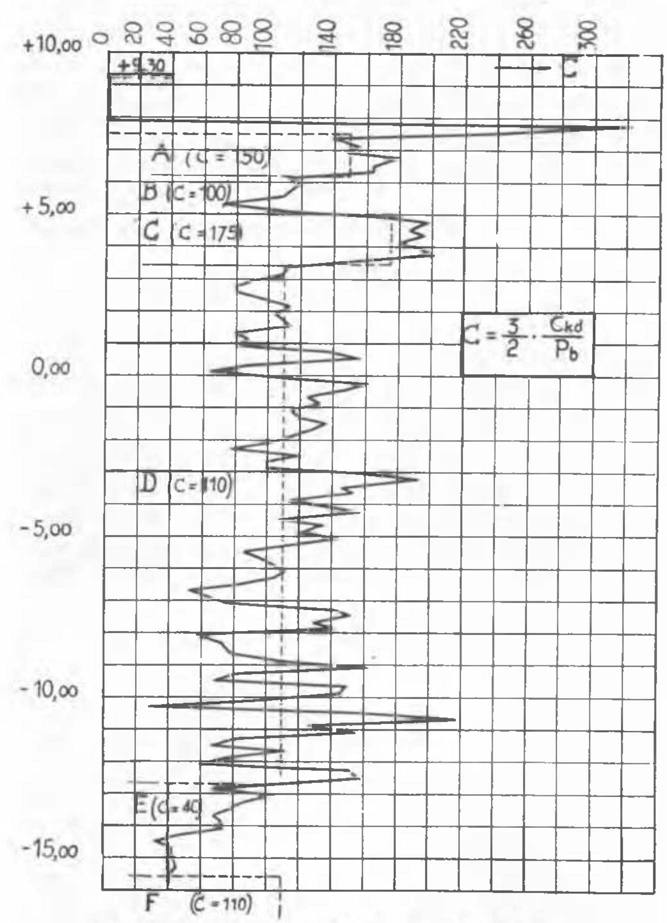
Buisman established the formula (1), by means of which it is possible to deduct for instantaneously compressible soils from the penetration resistance a lower limit for the constant of compressibility:

$$C = \frac{3}{2} \frac{C_{k,d}}{P_b} \qquad (1)$$



Deep sounding test I

FIG.1



C derived from deep sounding I

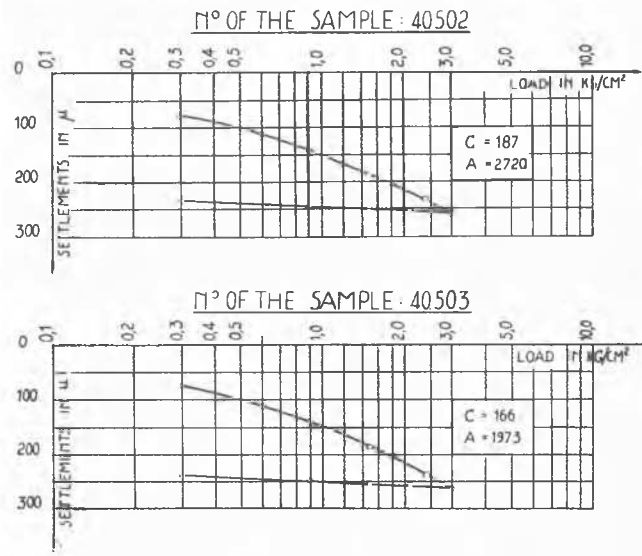
FIG.2

where C = the constant of compressibility.
$C_{k,d}$ = the measured penetration resistance (kg/cm^2)
p_b = the vertical effective stress.

By means of the formula (1) the diagram of the fig. 2 giving the variation of the constant of compressibility with depth has been deducted from the fig. 1.

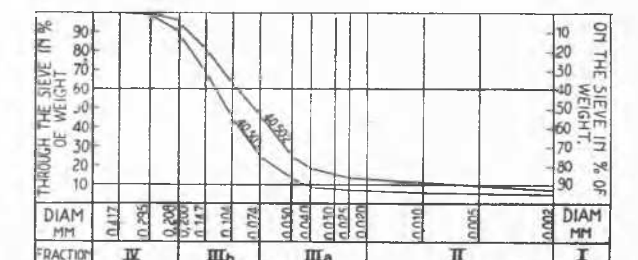
With the purpose to have for this report some more direct information concerning the nature of the soil, two samples were taken at the location of the bridge, on a depth of about 1.00 m underneath the soil surface. The physical and mechanical properties of these samples were determined in the laboratory. The granulometric curves and the plasticity index (fig. 3) indicate that the material is a little clayey fine sand; the percentages of voids correspond to a sand of medium compacity. The diagrams of the cell-tests (fig. 4) are characteristic for a sand. The consolidation diagrams of the fig. 5, give for the constant of compressibility C values of 166 and 187. These values are of the same order as those deducted from the sounding test for the layer A (fig. 2).

The settlements z are computed by means of the formula



Consolidation test

FIG.5



sample	origin.	depth under earth soil surface	granulometric size fraction IV	III b	III a	II	I	limits of Atterberg: liquid limit	plastic limit	plasticity index	organic content	chalk content	volume weight	dry weight	water content	percentage of voids	penetration value	nature
		m.	%	%	%	%	%	%	%		%	%	t/m^3	t/m^3	%	%	kg/cm^2	
40.502	Afsnee	1.05	3	49	35	6	7	25.0	16.7	8.3	0.1	1.34	2.080	1.790	16.8	32.5	6.5	little clayey
40.503	"	1.15	11	65	17	2	5	20.2	14.9	5.3	0.1	1.02	1.785	1.600	11.7	39.6	3.75	fine sand

Granulometric size.

FIG.3

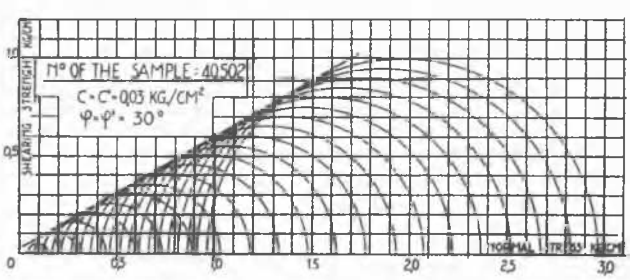


FIG.4a

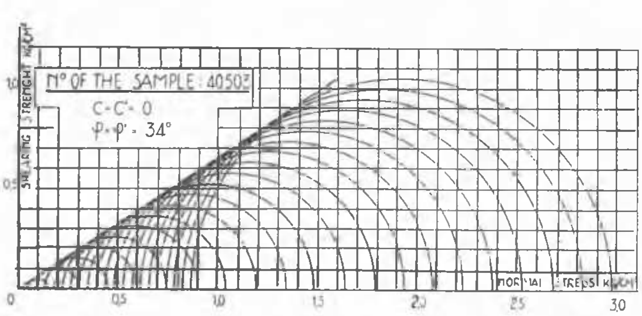
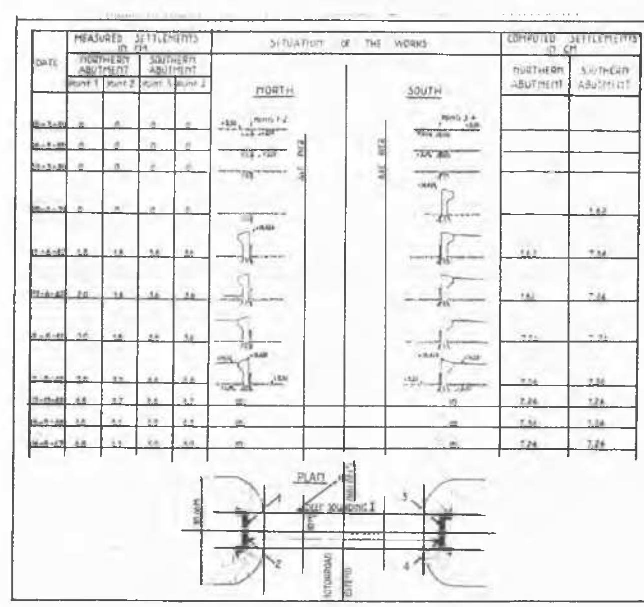


FIG.4b



Bridge at Afsnee - Results of the measured and computed settlements.

FIG.7

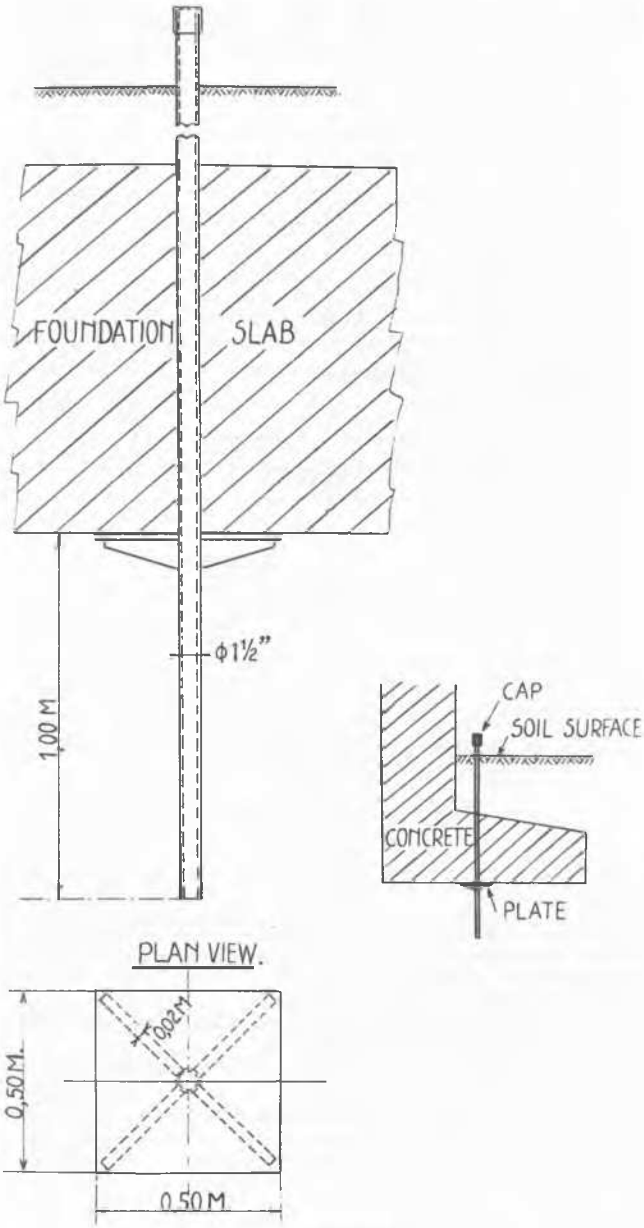
$$z = \int_{\infty}^{h_o} \frac{dh}{C} \, 2.3 \left[\log (p_o + \Delta p) - \log p_o \right] \qquad (1)$$

In this formula p_o = the natural vertical effective stress
Δp = the increase of the effective stress produced by the considered load.

The formula (1) lends itself very easily to an integration by means of a planimeter on a semi-logarithmic diagram.

The real diagram of variation of C with depth of the fig. 2 has been replaced in the calculation by the dotted diagram, which is composed of a certain number of constant values of C.

Till now only the abutments and the embankments have been constructed. The total weight of an abutment is 240 tons, correspond-



Plan view.

FIG.6

ing to a unitary pressure underneath the footing of 5,3 t/m². The maximum total height of the embankments is 5,00 m.

The calculations give the following results: settlement of the abutments produced by their own weight 1,62 cm
settlement of the abutments produced by the embankment 5,62 cm
total settlement produced by the own weight of the abutments and the weight of the embankment. 7,24 cm

On the other hand the settlements were measured as follows: As soon as a foundation pit was at the required depth, a heavy steel plate of 0,50 m x 0,50 m (fig. 6) was carefully placed at the bottom of the pit. In the plate was fixed a steeltube of 1,5 inch diameter, which was driven into the ground over a depth of 1 m. On the steeltube the desired number of lengthening tubes can be screwed, and on top a cap is placed. In the tube at the desired level a fine incision with a file can be made. The variation of the level of this incision can be regularly controled by means of a very accurate level apparatus, with respect to a point of reference located at a distance of at least 100 m from the bridge and the embankments.

The results of the measurements so performed are given in the fig. 7. The figure indicates each time the state of progress of the bridge construction at the moment of the measurements, and the final computed settlement corresponding to this state.

It is seen that the settlements corresponding to a certain load don't take place instantaneously, but take months to reach their final value. The measured settlements vary actually between 4,1 and 5,0 cm, to compare with a computed value of 7,24 cm.

The measured settlement under the own weight of the abutment is 1,8 cm (11.6.42); the corresponding computed settlement was 1,62 cm.

It is seen that the bigger part of the settlements of the abutments is produced by the weight of the embankments.

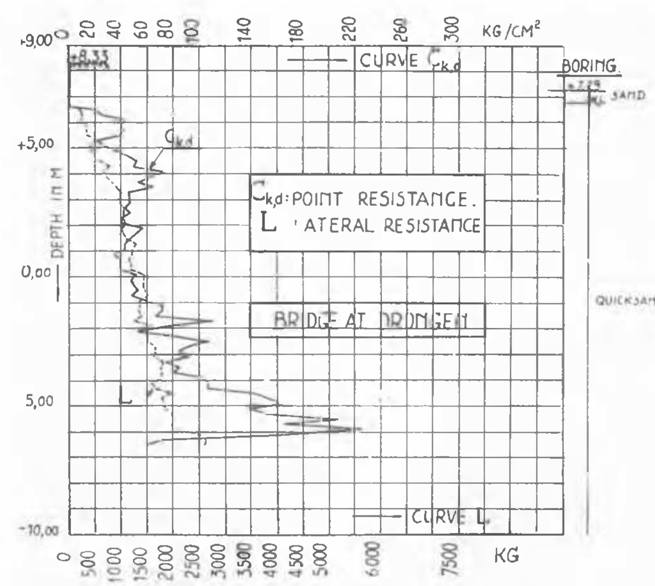
BRIDGE OVER THE MOTORROAD BRUSSELS-OSTEND AT DRONGEN (KEUZE).

The results of one of the sounding tests, and of a boring are given in fig. 8. The corresponding diagram of the constant of compressibility C is given in fig. 9.

Till now only the abutments and the embankments are constructed.

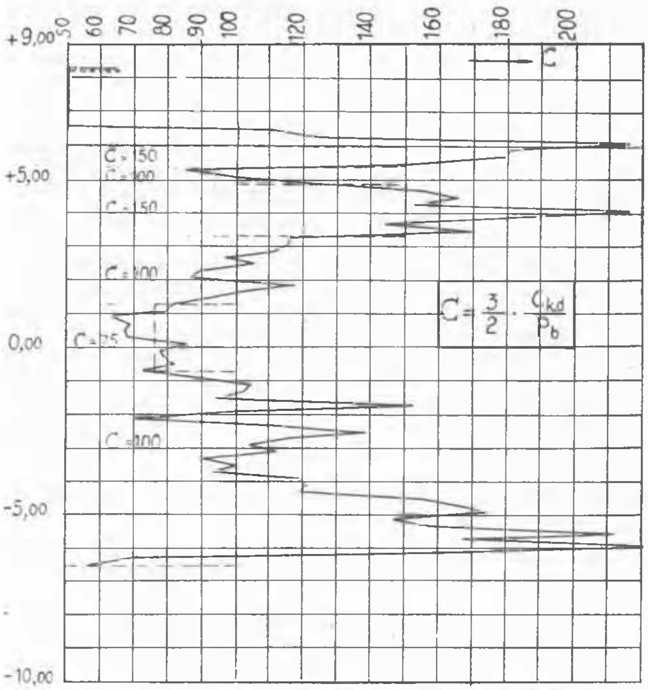
Own weight of an abutment : ± 200 tons.
Unitary pressure produced by the own weight of an abutment : 7,7 t/m².
Computed settlement produced by the own weight of the abutment : 1,84 cm.
Maximum height of the embankments: 6,90 m.
Width of the embankments at their base: 33,00 m.
Width of the embankments at their crest : 8,00 m.
Computed settlement produced by the weight of the embankments: 2,00 cm
Computed total settlement of the abutments produced by their own weight and the weight of the embankments :
1,84 + 2,00 = 3,84 cm.

The measured settlements are given in fig. 10, in function of the state of progress of the works.



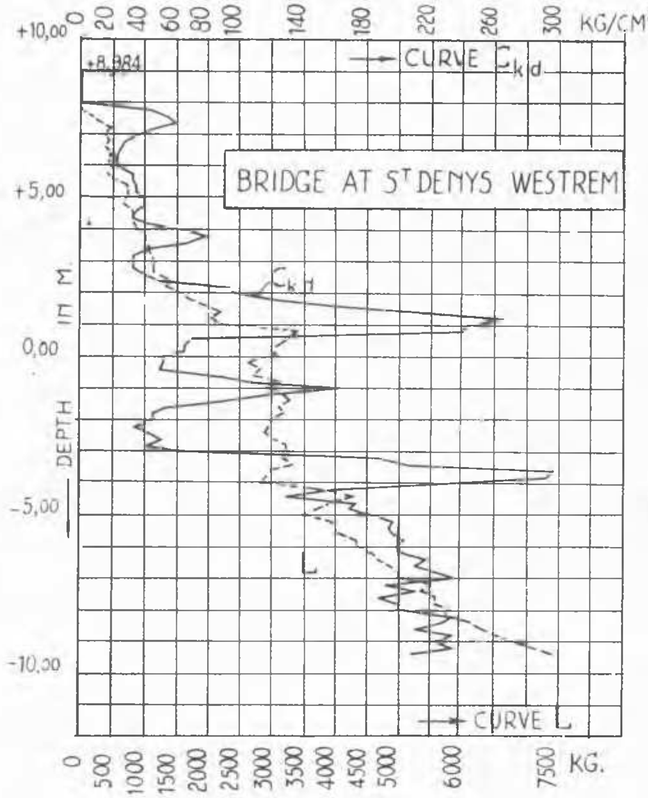
Deep sounding test II

FIG.8



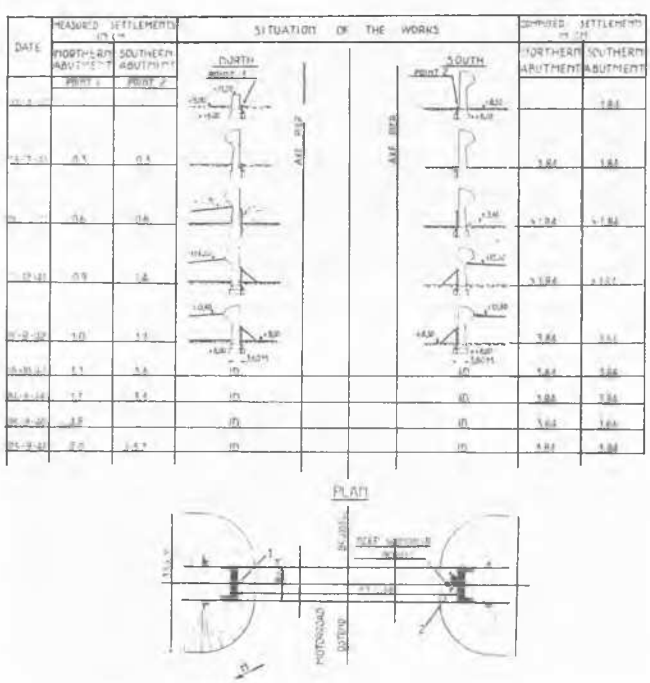
C derived from deep sounding Nr II

FIG.9



Deep sounding test I

FIG.11



Bridge at Drongen-Results of the measured and computed settlements.

FIG.10

The influence of time on the settlements is again clearly seen. The actual settlements vary between 2 and 3,7 cm; the corresponding computed value is 3,84 cm.

BRIDGE OVER THE RAILROAD KORTRIJK-GHENT IN THE MOTORROAD BRUSSELS-OSTEND AT ST.DENYS-WESTREM.

Only the two abutments and one of the embankments is yet constructed. Each abutment has a length of 24 m. and is composed of two independent parts.

Sounding test : see fig. 11.
Corresponding diagram of the constant of compressibility : see fig. 12.

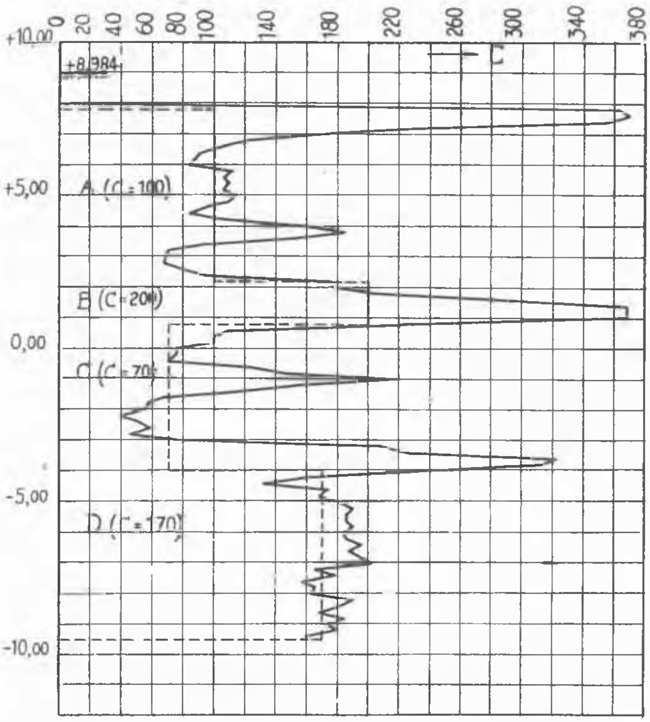
Unitary pressure produced by the own weight of the abutments :	8,14 t/m²
Computed settlement produced by the own weight of the abutments :	3,00 cm
Maximum height of the embankments:	6,625 m
Width of the embankments at their base :	40 m
Width of the embankments at their crest :	21 m
Computed settlement produced by the weigt of the embankments:	6,4 cm
Computed total settlement of the abutments produced by their own weight of the embankments :	9,4 cm.

The measured settlements are given in fig. 13, in function of the state of progress of the works.

The influence of time on the settlements is clearly indicated. The settlements of the abutment of the Brusselsside, whose embankment doesn't actually exist, vary between 0,7 and 1,6 cm., where as the computed settlement is 3,0 cm. The settlements of the abutment at the Ostend-side, whose embankment does exist, vary between 3,8 and 4,4 cm, to compare to a computed value of 9,4 cm.

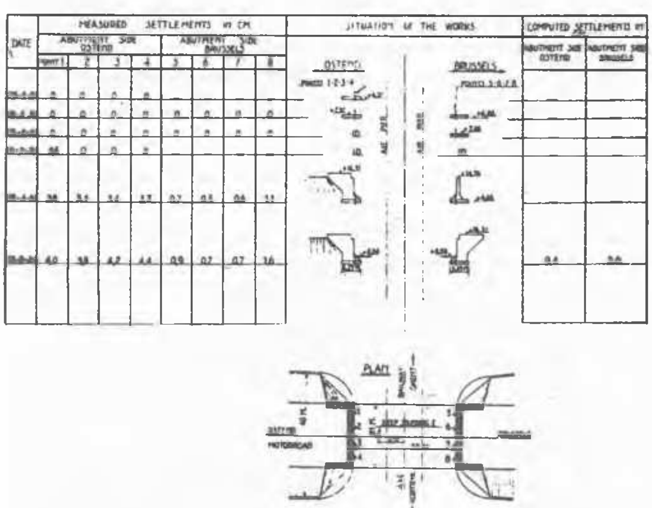
It must be noted that the computation of the settlements has been based on mean values of C, indicated by the dotted line of fig. 12.

If, instead of considering the values of C given in the second column of table I, the values of the third volumn of this table are taken, the so performed computation gives exactly the measured values of the settlements.



C derived from deep sounding I

FIG.12



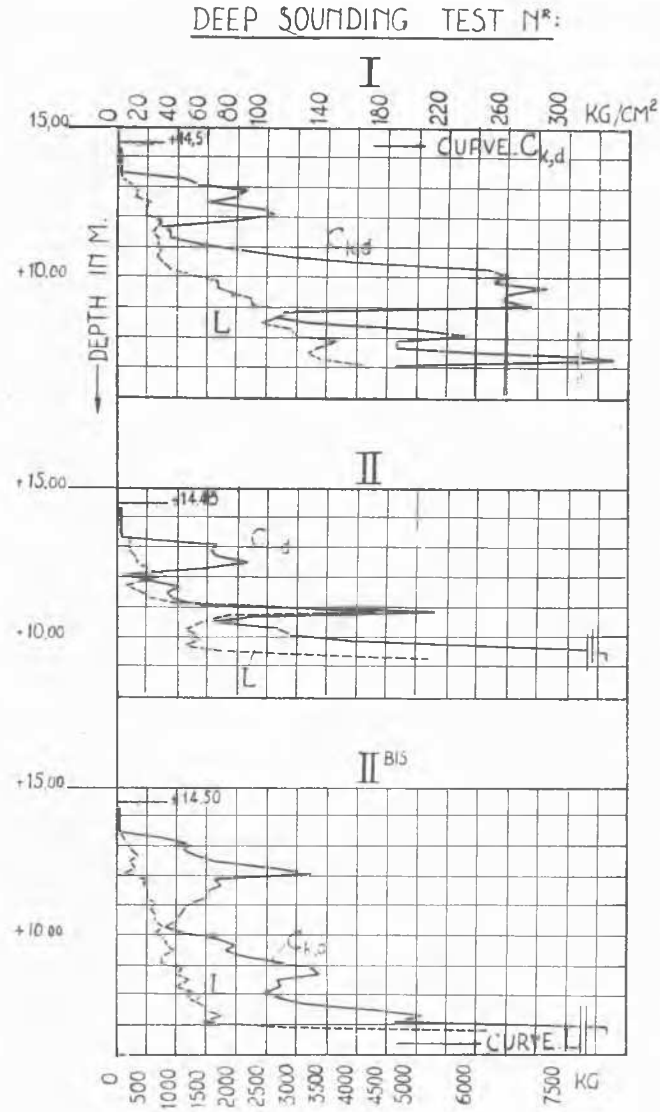
Bridge at St Denys-Westrem-results of the measured and computed settlements.

FIG.13

TABLE I (see fig. 12).

layer	lower limit	values of C corresponding to the measurements.
A	100	188
B	200	376
C	70	132
D	170	319

With the values of C given in the second column, an upper, and thus a safe value of the settlements is obtained. Nevertheless in layers



Bridge at Beernem

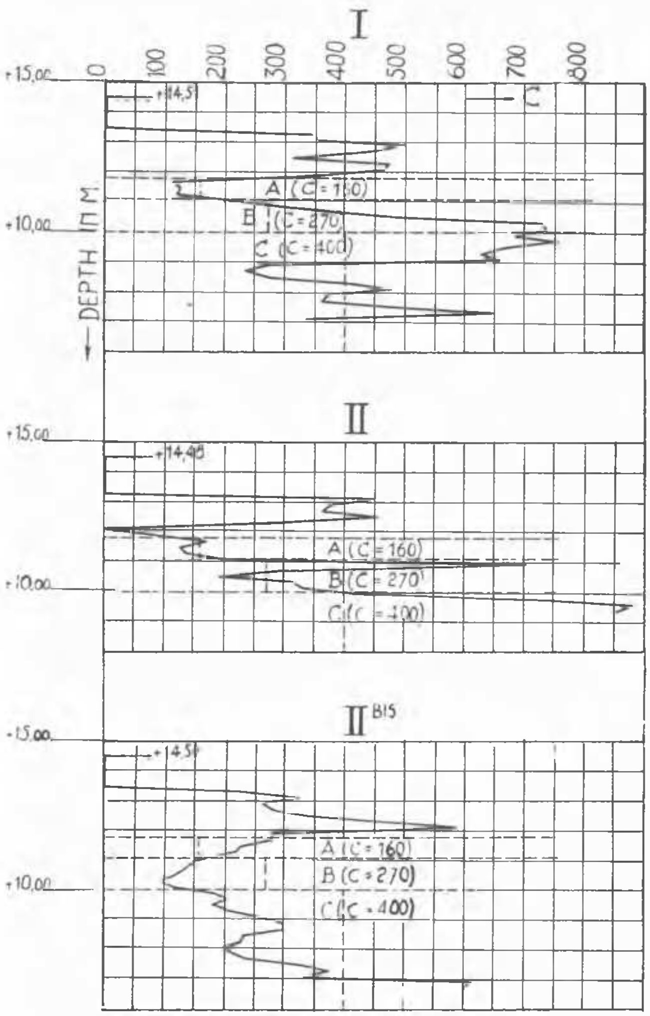
FIG.14

with a lenticular composition it is possible that the settlements are not determined primarely by the mean value of the constant of compressibility, but chiefly by the constant of compressibility of the least compressible parts of the layer. When the figures of the third colomn of the table I are compared with the values of the real diagram of C (fig. 12), it seems that there must be sought the reason for the discrepancy between the measured and computed settlements.

BRIDGE OVER THE MOTORROAD BRUSSELS-OSTEND IN THE HIGHWAY Nº 70 AT BEERNEM.

The bridge itself was completely achieved when the measurements of the settlements were started. For this reason the unknown quantities x_1 to x_6 appear in the columns of fig. 16.

The only measured settlements are those produced by the weight of the embankments.
Diagram of the sounding tests : fig. 14
Diagram of C for the 3 performed tests: fig.15.
At the same depth the 3 performed sounding tests give rather different values. Taking at each depth the mean of the obtained values, the



C derived from deep soundings

FIG.15

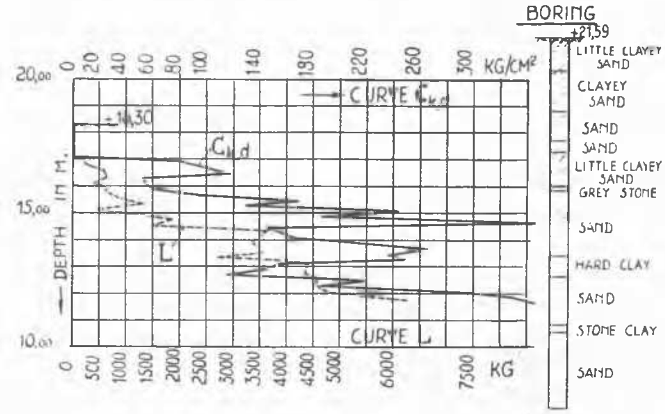
compressibility of the soil has been finally assumed to follow the dotted line of the fig.15.

Own weight of the pier : 215 tons.
Reaction of the bridge on the pier : 250 tons.
Effective pressure underneath the footing of the pier : 13,25 t/m^2.
Own weight of the abutment and reaction of the bridge 665 tons.
Effective pressure underneath the footing of an abutment 12,82 t/m^2.
Embankments : maximum height 5,68 m.
width at the base 24 m.
width at the crest 11 m.
Computed settlement of the abutments produced by the weight of the embankments : 0,87 cm.

The measured settlements are given in fig. 16. The influence of time can be seen. The measured settlements of the abutments are actually x + 0,5 cm, to compare with a computed settlement of x + 0,87 cm; the pier has practically not been influenced by the embankments.

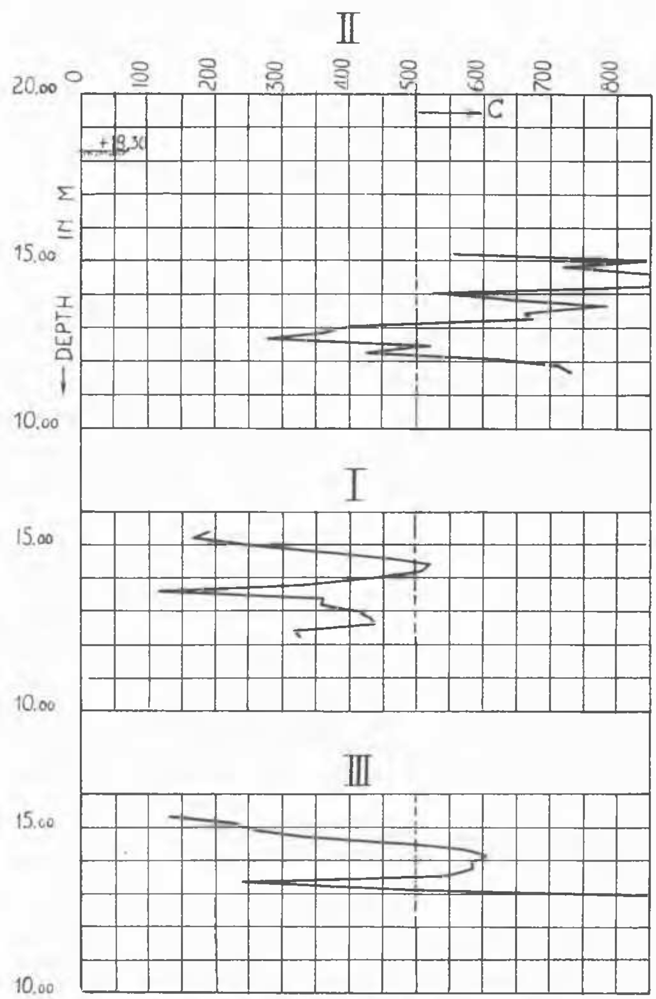
BRIDGE OVER THE MOTORROAD BRUSSELS-OSTEND IN THE STERRESTREET AT AALTER.

At the site of the bridge the motorroad is located in a cut with a depth varying from 3,30 m to nearly 5,00 m.



Bridge at Aalter-Deep sounding test II

FIG.17



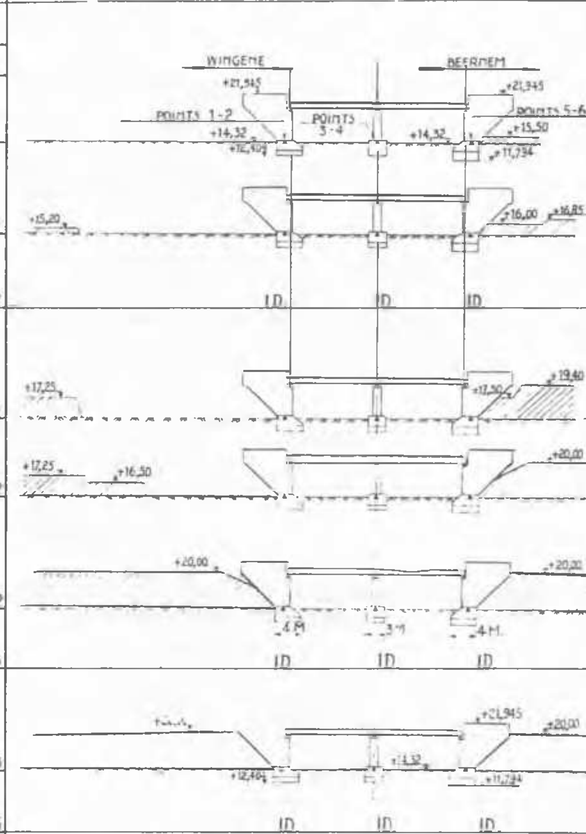
C derived from deep soundings

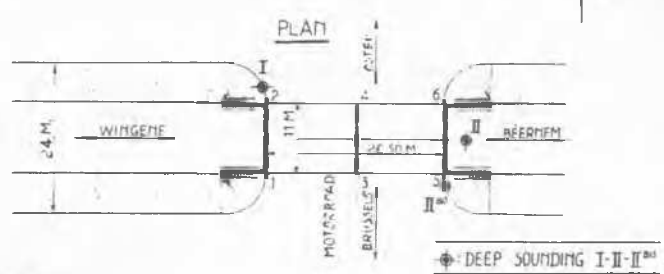
FIG.18

Sounding test + boring : see fig. 17.
Diagrams of C : see fig. 18.
For C a mean value of C = 500 has been adopted for the computations.
Own weight of a pier : 140 tons.
Effective pressure underneath a

DATE	MEASURED SETTLEMENTS IN CM.						COMPUTED SETTLEMENTS IN CM.		
	ABUTMENT SIDE WINGENE		PIER		ABUTMENT SIDE BEERNEM		ABUTMENT SIDE WINGENE	PIER	ABUTMENT SIDE BEERNEM
	POINT 1	POINT 2	POINT 3	POINT 4	POINT 5	POINT 6			
12-7-41	X_1	X_2	X_3	X_4	X_5	X_6			
29-7-41	X_1+0	X_2+0	X_3+0	X_4+0	$X_5+0.5$	$X_6+0.2$			
5-8-41	X_1+0	X_2+01	X_3+0	X_4+0	$X_5+0.5$	$X_6+0.2$			
4-9-41	X_1+01	X_2+01	X_3+0	X_4+0	$X_5+0.5$	$X_6+0.2$			
10-10-41	X_1+01	X_2+01	X_3+0	X_4+0	$X_5+0.5$	$X_6+0.2$			
8-12-41	X_1+01	X_2+01	X_3+0	X_4+0	$X_5+0.5$	$X_6+0.2$			
15-9-41	X_1+02	X_2+01	X_3+0	X_4+0	$X_5+0.5$	$X_6+0.3$	$X_1+0.87$	X_3+0	$X_5+0.87$
11-9-42	X_1+02	X_2+01	X_3+0	X_4+0	$X_5+0.5$	$X_6+0.3$	$X_1+0.87$	X_3+0	$X_5+0.87$
29-9-47	X_1+06	$X_2+0.5$	$X_3+0.1$	X_4+0	$X_5+0.5$	$X_6+0.5$	$X_1+0.87$	X_3+0	$X_5+0.87$

SITUATION OF THE WORKS





Bridge at Beernem Results of the measured and computed settlements.

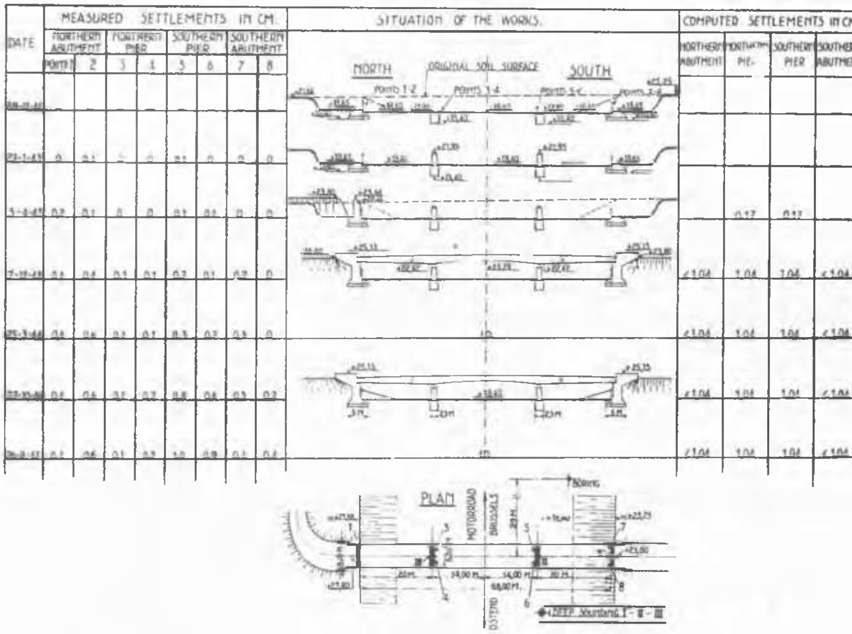
FIG.16

pier produced by its own weight: 6 t/m^2.
Computed settlement produced by the own weight of a pier : 0,17 cm.
Increase of the pressure underneath the pier produced by the weight of the bridge itself : 23 t/m^2.
Total effective pressure underneath the pier : 6 + 23 = 29 t/m^2.
Computed settlement produced by the weight of the bridge itself : 0,87 cm.
Total computed settlement of the pier : 0,17 + 0,87 = 1,04 cm.
For the abutments the computation of the settlements has not been performed, these settlements being " a priori " smaller than those of the much more loaded piers.

The measured settlements are given in fig. 19. For the abutments, they are actually located between 0,4 and 0,6 cm; for the piers the difference between the northern and the southern one is considerable; the first settles only from 0,2 cm, the second from 1 cm. This latter value is very near the computed value.

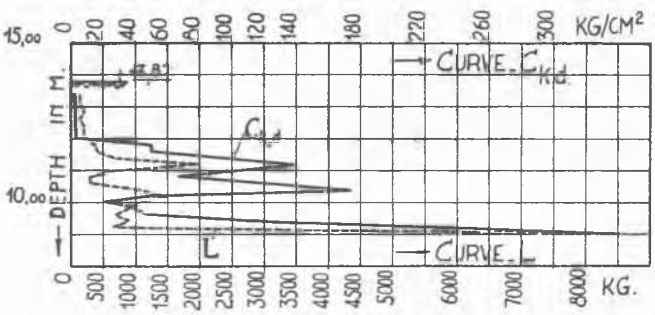
BRIDGE OVER THE MOTORROAD BRUSSELS-OSTEND IN THE WELLINGSTREET AT BEERNEM.

Sounding test : see fig. 20.
Diagram of C : see fig. 21.
Own weight of an abutment : 813 tons.
Reaction of the bridge on the abutments : 130,5 tons.
Total effective pressure underneath the abutment produced by its own weight and the reaction of the bridge itself : 8,65 t/m^2.
Computed settlement of the abutment produced by its own weight and the reaction of the bridge itself : 0,81 cm.
Embankments : maximum height : 6,00 m
width at the base: 32,50 m
width at the crest:12,00 m.
Settlement of the abutments produced by the weight of the embankments : 0,4 cm.
Total computed settlement of an abutment: 0,82 + 0,4 = 1,21 cm.
Own weight of the pier : 283 tons.



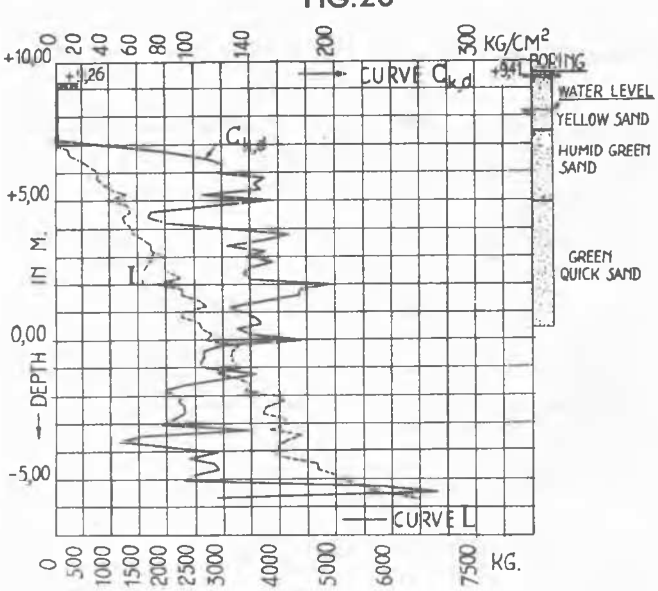
Bridge at Aalter - Results of the measured and computed settlements.

FIG.19



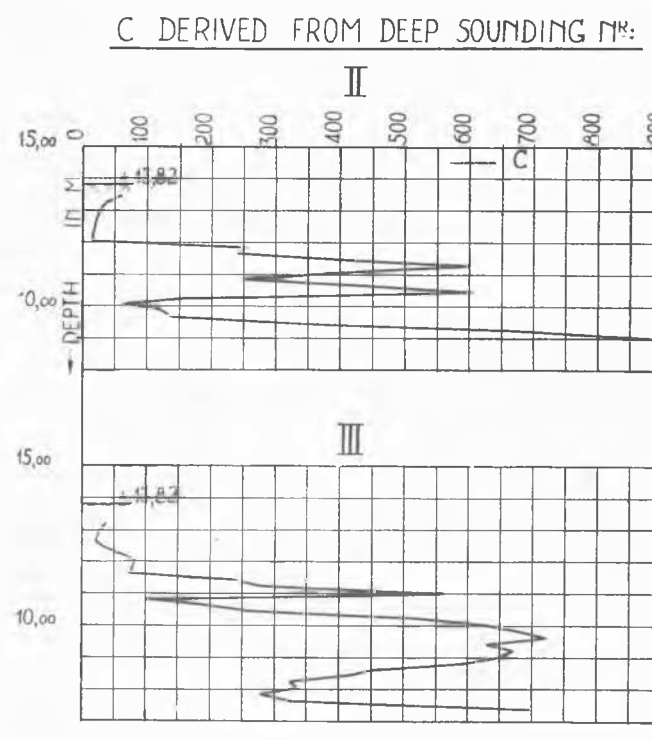
Bridge at Beernem (Wellingstreet)
Deep sounding test II

FIG.20



Bridge at Gentbrugge-Deep sounding test I

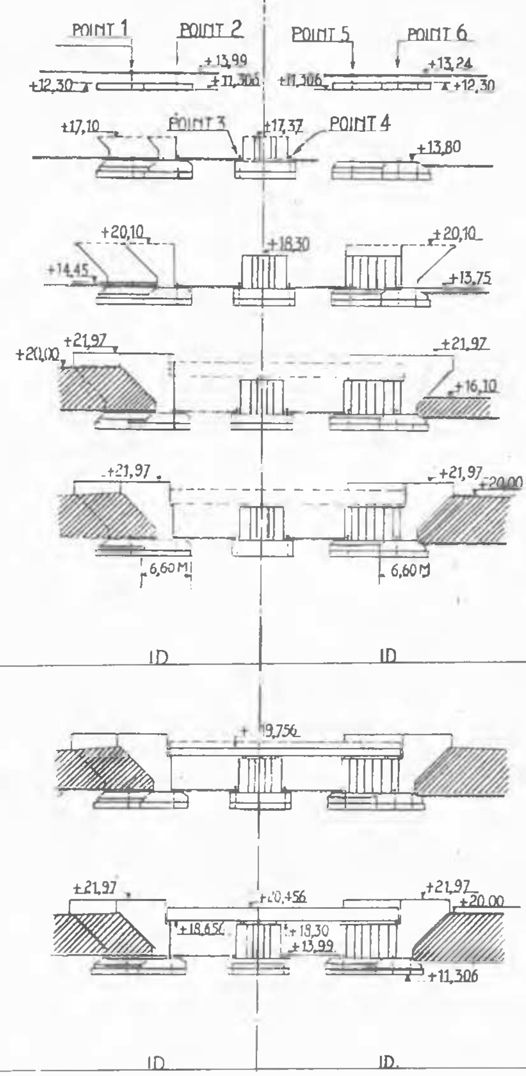
FIG.23



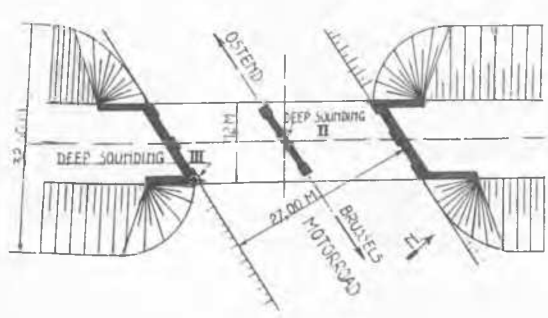
C derived from deep soundings

FIG.21

DATE	MEASURED SETTLEMENTS IN CM.						SITUATION OF THE WORKS	COMPUTED SETTLEMENTS IN CM.		
	SOUTHERN ABUTMENT		PIER		NORTHERN ABUTMENT			SOUTHERN ABUTMENT	PIER	NORTHERN ABUTMENT
	POINT 1	2	3	4	5	6				
13-10-41	0	0	—	—	0	0		—	—	—
8-12-41	0	0	0	0	0,1	0,1		—	—	—
23-4-42	0.1	0	0	0,1	0,1	0.1		—	—	—
11-8-42	0.2	0,2	—	0.1	0.3	0.2		—	—	—
9-9-42	0.7	0.4	0,5	0.1	1,0	0,3		—	—	—
13-11-42	0.7	0.4	0.6	0.2	1.0	0.3	ID / ID	—	—	—
26-1-43	0,9	0.5	0,6	0.2	1.0	0.6		—	—	—
29-3-43	1,4	0.5	0,6	0.2	1,0	0,6		—	—	—
30-9-47	2.0	1.0	0.6	0.7	1.2	1.2	ID / ID.	1,21	1,33	1,21

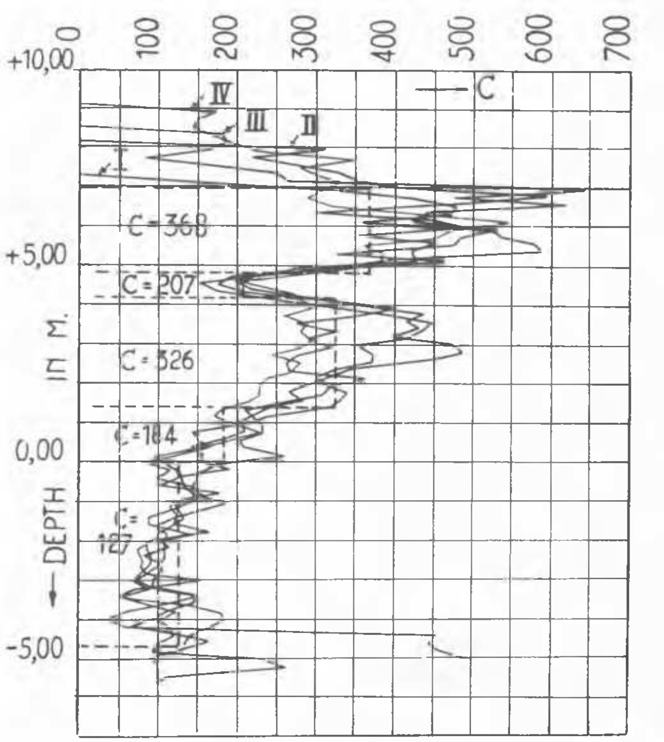


PLAN



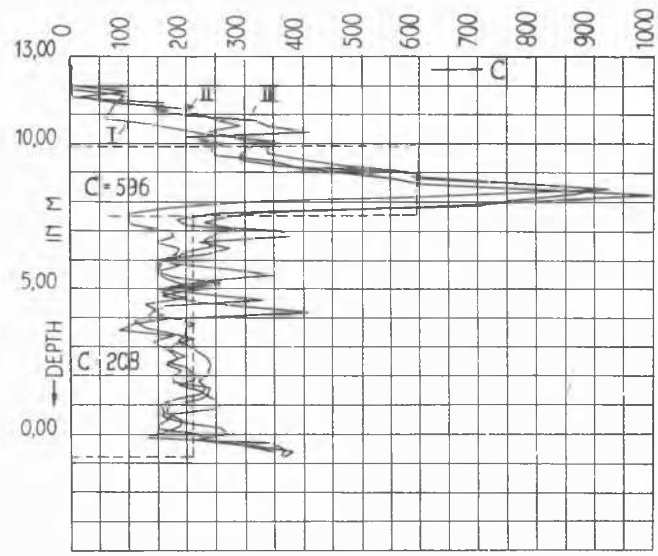
Bridge at Beernem (Wellingstreet) Results of the measured and computed settlements.

FIG.22



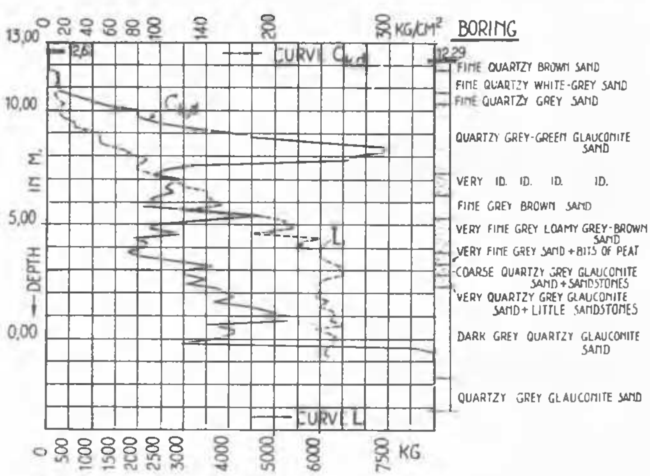
C derived from deep sounding Nr I. II. III. IV.

FIG.24



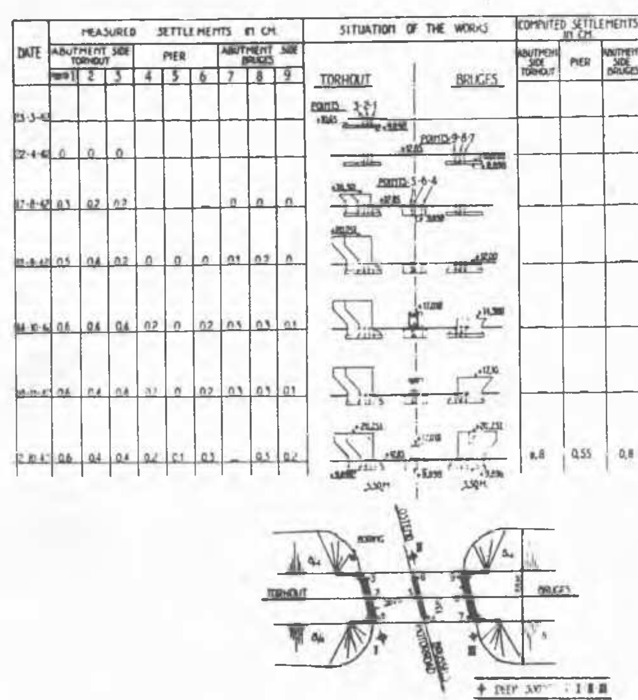
C derived from deep sounding Nr I. II. III.

FIG.27



Bridge at Loppem. Deep sounding test I

FIG.26



Bridge at Loppem. Results of the measured and C computed settlements

FIG.28

Reaction of the bridge on the pier : 435 tons.
Total effective pressure underneath the pier : 17,5 t/m².
Total computed settlement of the pier: 13,3 mm.
The measured settlements are given in fig. 22.

BRIDGE OVER THE RAILWAY AROUND GHENT IN THE HIGHWAY GHENT-BRUSSELS AT GENTBRUGGE.

The bridge consists of two abutments and two piers, supporting an independent span and two continuous spans.

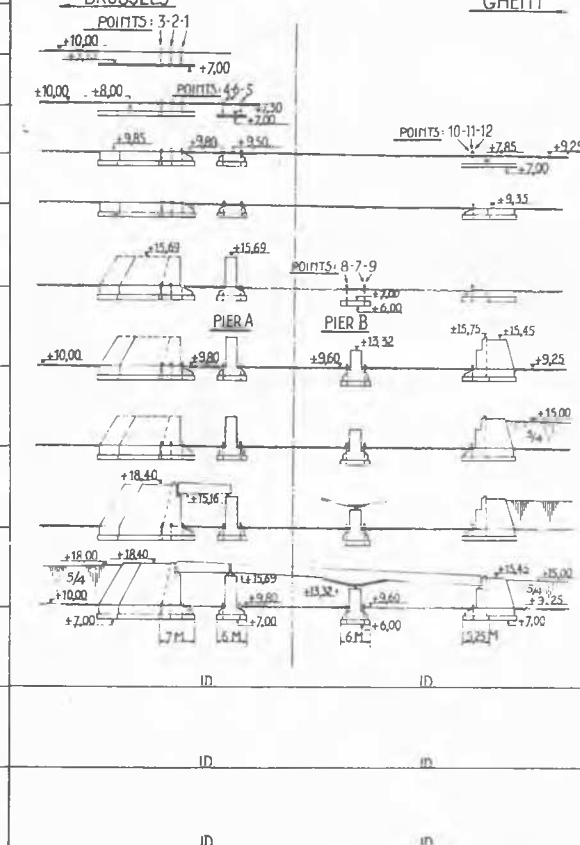
Sounding test : see fig. 23.
Diagram of C : see fig. 24.

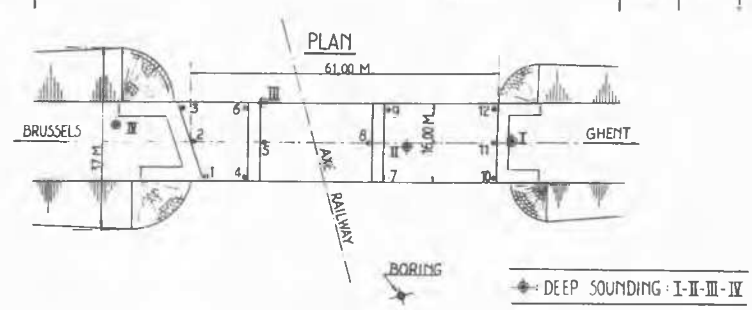
Own weight of the abutment "Brussels":	3250 ton
Reaction of the bridge on the abutment "Brussels" :	14,5 ton/r.m.
Own weight of pier A (fig. 25):	1087 ton
Reaction of the bridge on pier A :	38,5 ton/r.m.
Own weight of pier B (fig. 25) :	972 ton.
Reaction of the bridge on pier B :	84 ton/r.m.
Own weight of the abutment "Ghent":	1650 ton.
Reaction of the bridge on the abutment "Ghent" :	24 ton/r.m.
Embankments: width at the base :	37,00 m.
width at the crest :	16,00 m.
maximum height Brussels' side:	8,00 m.
maximum height Ghent's side:	5,75 m.

Total computed settlements under all effects, based on the C values, given by the dashed lines of fig. 24 :

DATE	MEASURED SETTLEMENTS IN CM. Abutment side Brussels			Pier A			Pier B			Abutment side Ghent			COMPUTED SETTLEMENTS IN CM. Abutment side Brussels	Pier A	Pier B	Abutment side Ghent
	Point 1	2	3	4	5	6	7	8	9	10	11	12				
1-5-39	0	0	0													
5-5-39	0.1	0.1	0.1	0	0	0										
26-5-39	0.5	0.4	0.4	0.3	0.2	0.3	—	—	—	0	0	0				
2-6-39	—	0.4	0.4	0.3	0.3	0.3				0.3	0.2	0.2				
29-6-39	0.9	0.8	0.6	0.6	0.6	0.6	0	0	0	—	0.3	—				
16-8-39	0.9	0.8	1.0	—	0.6	—	0.4	0.7	0.4	1.0	0.8	0.8				
7-10-39	1.0	0.8	1.0	0.7	0.7	0.8	0.4	—	0.4	1.0	0.8	0.8				
6-12-39	1.2	1.1	1.1	0.8	0.7	0.9	0.5	0.8	0.7	1.4	1.3	1.2				
17-4-40	1.2	1.2	1.2	1.1	1.0	1.1	1.2	[illegible]	1.1	1.5	1.3	1.2	2.97	2.03	2.12	3.1
16-1-42	3.0	3.2	3.4		[illegible]	—	2.8	—	—		2.6		—	—	—	—
21-8-42	—	3.4				—	2.8	—		—	2.7	—	-	-	-	-
3-10-47	—	—	—	—	—	—	—	—	—	—	2.8	—	-	-	-	-

SITUATION OF THE WORKS





Bridge at Gentbrugge-Results of the measured and computed settlements.

FIG.25

Abutment "Brussels" :	2,97 cm.
pier A :	2,03 cm.
pier B :	2,12 cm.
abutment "Ghent"	3,09 cm.

The measured settlements are given in fig. 25. The bridge is in service since several years and presents no fissures.

BRIDGE OVER THE MOTORROAD BRUSSELS-OSTEND IN THE WAY TORHOUT-BRUGES AT LOPPEM.

At this moment only the abutments and the pier are achieved.
Sounding test : fig. 26.
diagram of C : fig. 27.
Own weight of the abutment : 800 ton.
Own weight of the pier : 350 ton.
The dashed lines of fig. 27 give the mean value from all performed tests over the considered height.
Computed settlements, under the own weight of the abutments and the pier, based on the C values, given by the dashed lines of fig. 27:

abutments :	0,80 cm.
pier :	0,55 cm.

The measured settlements are given in fig. 28.

CONCLUSION.

For several bridges founded on sand the settlements occuring during and after construction were measured, and the values thus found compared to those deducted from deep sounding tests.

Generally there is a fair agreement between the calculated and measured settlements, taking into account that the former ones are an upper limit.

In case of instantaneously compressible layers, in which it is very difficult to take undisturbed samples, the results of deep sounding tests are very valuable, because from them can be computed an upper limit of the settlements to be expected.