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Subsidence in Bridge Constructions on the German State Arterial Roads.

Setzungsbeobachtungen an Brückenbauten der Reichsautobahnen.

Observations d'affaissement sur les ouvrages d'art du réseau allemand d'autostrades.

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I. Introduction.

Early recognising the importance of examining the character of the soil, the General Inspector of the German highways board, soon after taking up his post, ordered that the soil was to be rested with respect to its carrying capacity according to the most modern views of earthwork mechanics, before any new sections of the state motorcar highways were started. In the course of 1934, each of the separate head offices entrusted with the work of constructing the state motorcar highways received its own testing station for the purpose not only of investigating the condition of the ground under the highways, but also of allowing, from suitable tests of the soil conditions under the intended structures, a decision to be made regarding the most suitable type of foundations or bridge systems. Accordingly, the soil testing stations are equipped with apparatus which allow the compressibility and permeability of soil samples in their original state to be determined, and consequently the probable amount of settling to be expected. Apart from the convenience of being able to form an approximate idea of the magnitude of the probable settling, the purpose of such an investigation of the soil, in consequence of the great number of works of all kinds which are to be erected in the future for the state motorcar highways on similar soil, consisted mainly in:

1. classifying the upper strata in the whole of Germany, with regard to its carrying capacity and compressibility,
2. checking the theory of settling used in calculations, by comparing the theoretical settling with the settling actually occurring,
3. the possibility of obtaining greater economy when designing new bridge structures.

The second and third points depend closely on each other, since the obtaining of greater economy in construction is necessarily conditioned by the figures used when calculating the amount of settling.

* Vocabulary for illustration texts at end of article.

The engineers and geologists employed in the soil testing stations of the state motorcar highways have had only slight opportunity to attend courses on "earthwork mechanics" in their student days, since hitherto only a few technical colleges include this subject in their curriculum. This circumstance, also the great difficulty in obtaining assistants, and last but not least the speed at which the work had to be carried out, make it easy to understand that the investigations on settling for the works hitherto completed are to a certain extent incomplete. In spite of that,

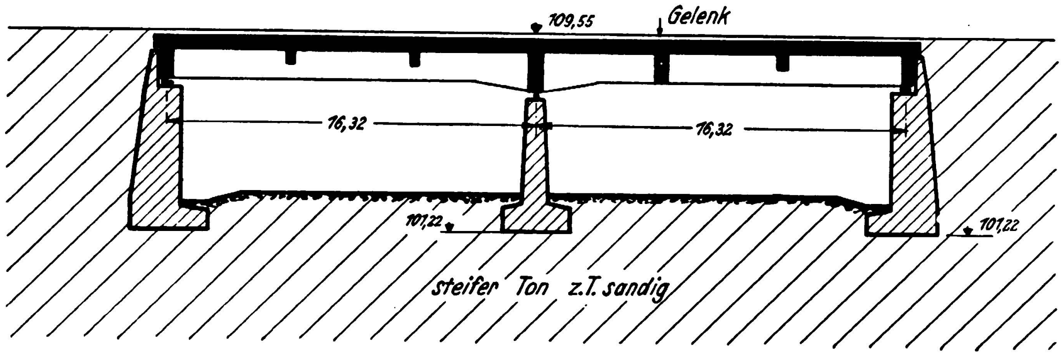

Fig. 1.

the amount of information now available has already allowed interesting conclusions to be drawn, and the purpose of the present report is to mention them and to evaluate them.

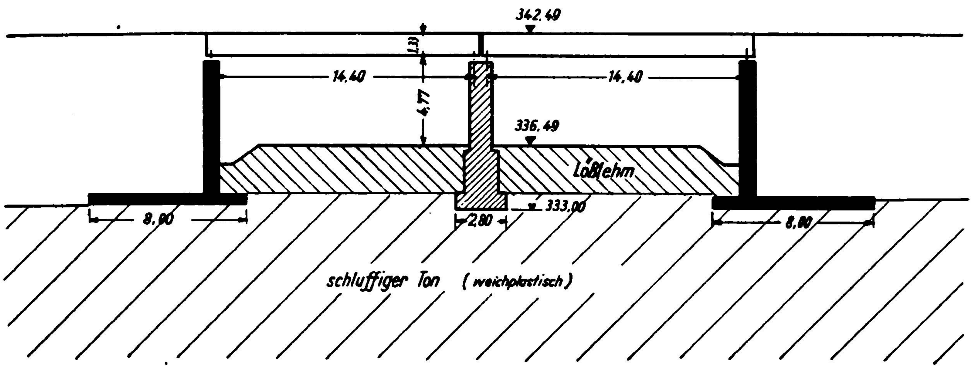

Fig. 2.

II. Theory of the prediction of the amount of settling through pure compression of the subsoil.

Compactness of a soil is conditioned by its porosity. It is thereby assumed that the separate particles of the soil and also the water, may be regarded as comparatively incompressible. Reduction of porosity and the squeezing of water out of the voids, go hand in hand. The more permeable the soil, the quicker can the moisture contained in it be expelled, i. e. the quicker will it be compressed by a superimposed load. In the case of sands, this process takes place almost immediately, but in the case of more compact soils (clay, loam, etc.) it may last even for years, depending on the permeability and thickness of the layers. Between the two extremes of sand and compact clay, the number of different kinds of soil is very great and consequently also the number of different rates of settling to be expected.

A further important factor is the degree of compressibility of the soil. Sands possess little compressibility; clays, in consequence of their much greater volume of voids, possess great compressibility. If, therefore, a sand sample and a clay sample are loaded to the same extent, the clay will generally be compressed more than the sand. Thorough investigations have been made by *Terzaghi*[1] concerning the influence of the shape of the particles, as well as of the structure of the ground.

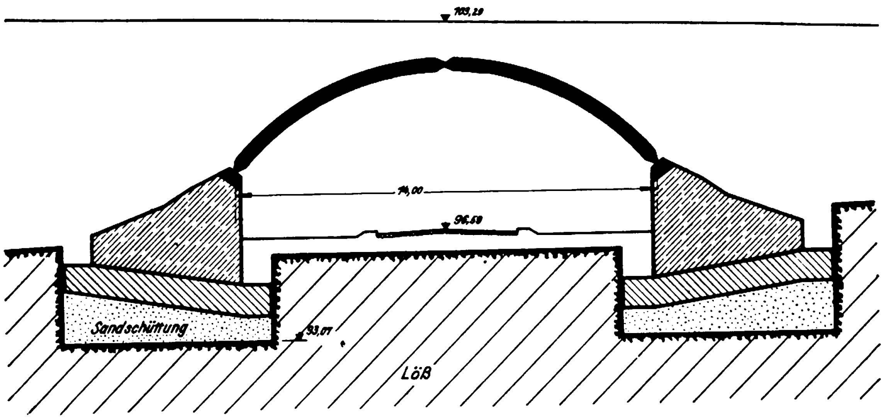

Fig. 3.

The compression test gives answers to two questions:

1. to what degree the soil sample could be compressed under a given load, and
2. at what rate the compression takes place.

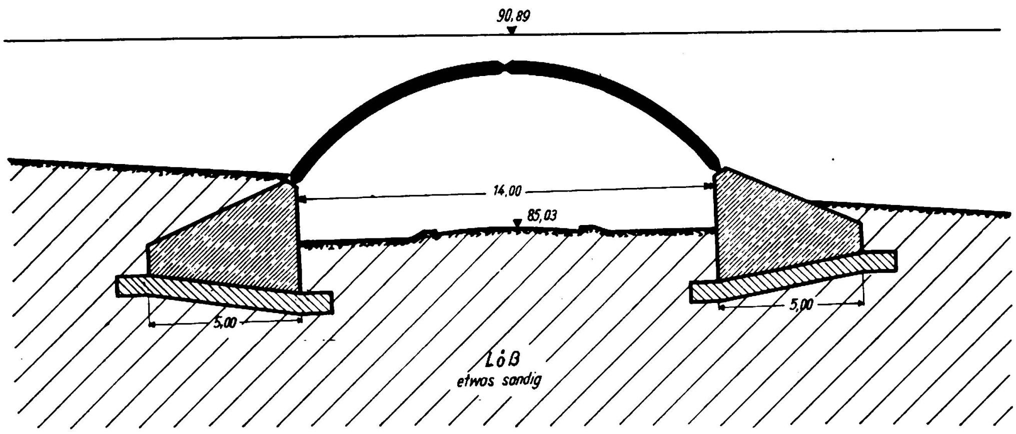

Fig. 4.

It would lead us too far to enter more into detail concerning the question of pre dicting the amount of settling. *Terzaghi* and *Fröhlich* have dealt thoroughly with the question of compression of clay soils in a recently published work[2], where they give simple formulae and tables for the degree and rate of compression.

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[1] *K. v. Terzaghi:* „Erdbaumechanik", Vienna 1925; „Festigkeitseigenschaften der Schüttungen, Sedimente und Gele", *Auerbach* und *Hort*, Handbuch der Mechanik, Vol. IV, Leipzig 1931; „Ingenieurgeologie", *Redlich-Terzaghi-Kampe*, Vienna and Berlin 1929.

[2] *K. v. Terzaghi* and *O. K. Fröhlich:* „Theorie der Setzung von Tonschichten", Leipzig and Vienna 1936.

III. Observations made on the settling of a number of bridge structures on the German motorcar highways.

Although, in consequence of the circumstances mentioned above, only a comparatively small number of predictions of settling could be calculated from the laboratory tests carried out on corresponding soil samples, the not yet complete analyses of the settlings show, however, a certain agreement between the calculated

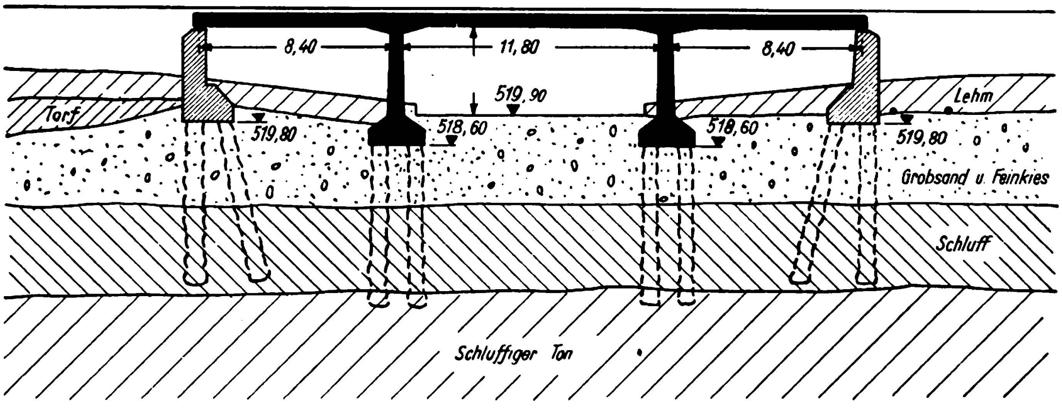

Fig. 5.

and the observed values, which is exact enough for practical purposes. In this connection it is remarkable that the predicted amount of settling based on theory is always greater than the amount actually observed. In some cases the difference attained a maximum of 100%, i. e. instead of 100 mm as calculated, the actual settling was only about 50 mm.

The following examples contain only the most essential data required to allow the examples to be understood and compared. Diagrammatic sectional sketches of structures and subsoil, as well as graphic representations of the measured settlings, have, owing to the space available, been given for only the most interesting cases.

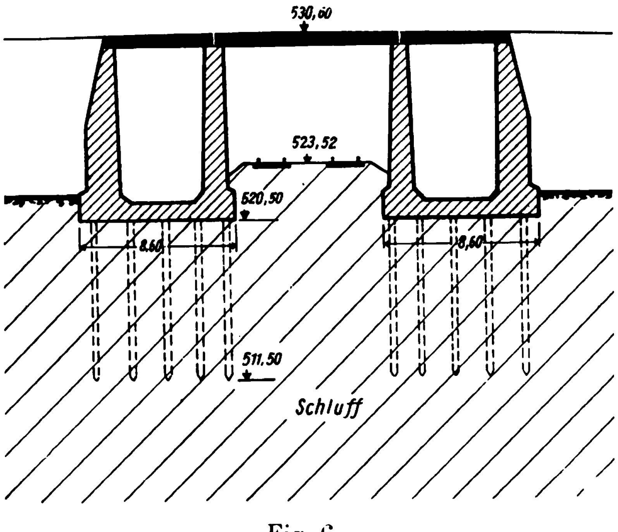

Fig. 6.

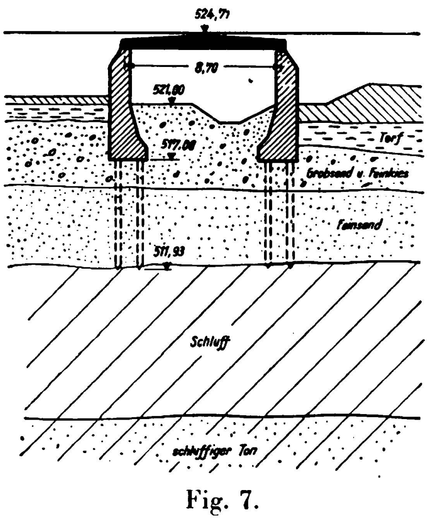

Fig. 7.

1. Work No. 128, km 265.885, Hanover Office. Reinforced concrete two-bay cantilever girder with suspended girders (Fig. 1). Spread footings on deep compact

clay (40% < 0,002 mm, natural water content about 31%), mean foundation pressure 1.4 kg/cm² below abutments and piers. Completed June 1935, settlings in April 1936 were maximum 54 mm for the abutments and 56 mm for the pier. Calculated settling 100—150 mm total. Settling still continues, no damage.

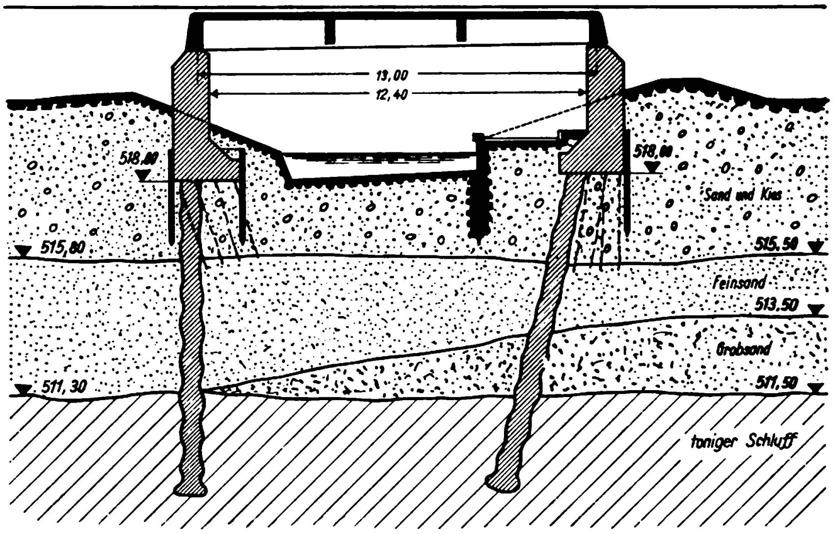

Fig. 8.

2. Work at km 28.5, Cologne Office. Two steel plate continous girders each of 6 bays on reinforced concrete piers, total length 540 m, bay lengths each 45 m. Spread footings on stiff clay up to 6 m thick, under which irregularly deposited beds of gravel and marl, also rock. Completed December 1935, maximum settling of the piers 52 mm, last measurement in March 1936. Settling still continues, no damage.

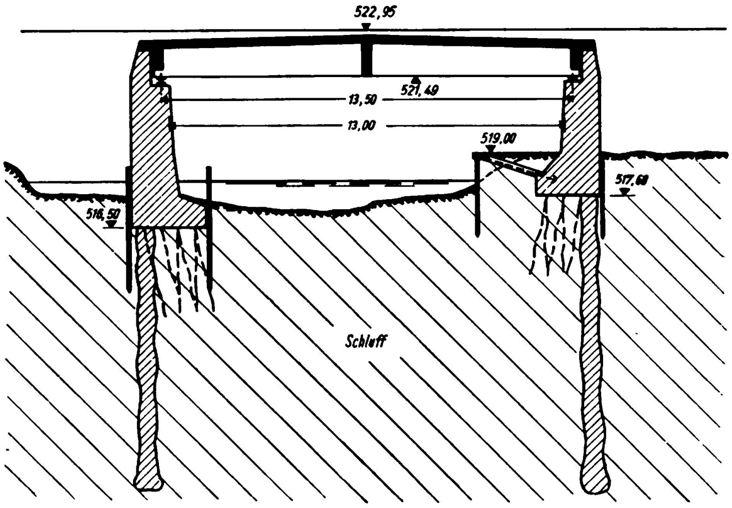

Fig. 9.

3. Work at km 38.982, Dresden Office (Fig. 2). Reinforced concrete deck girders, 2 bays each 14,4 m span. Spread footings on very plastic siltlike clay up to 12 m thick, natural water content 16.0—21.3%, flow limit 29.9—56.3%, rolling limit 15,7—18.8%. Foundation pressure about 1.5 kg/cm² for abutments and 1.0 kg/m² for piers. Completed August 1935. Predicted settlings about 150 mm for abutments and 60 mm for piers, actual settlings about 46 mm for abutments and 25 mm for piers, last measurement August 1935. Settling has stopped, no damage.

4. Work W 26, km 48.425, Halle Office. Fixed arch (vaulted culvert), Spread foundations on soft clayey silt about 1.50 m thick, under which sand. Foundation pressure 2.75 kg/cm². Completed February 1936, predicted settling about 95 mm, actual settling 50 mm. Settling has stopped.

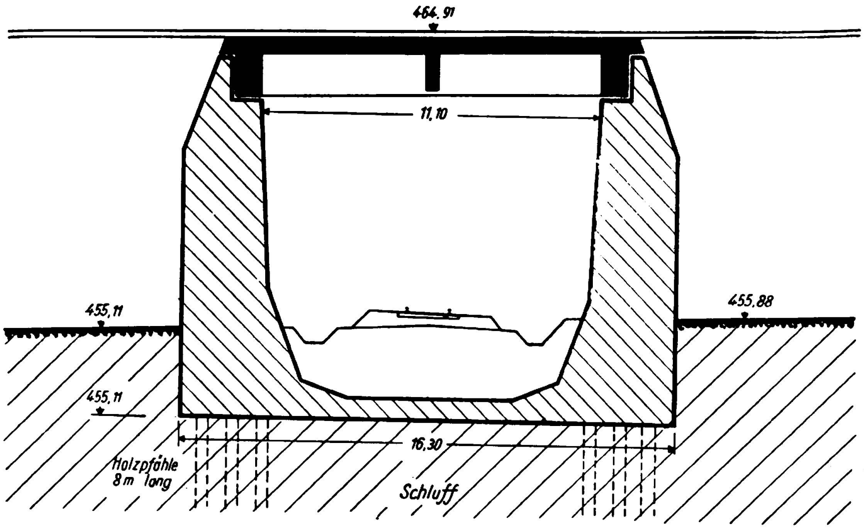

Fig. 10.

5. Work No. W 45a, km 15.135, Halle Office. Closed reinforced concrete frames, spread foundations, foundation pressure about 1.1 kg/cm², subsoil 8—10 m sandy clay, under which sand. Completed November 1935, predicted settling about 220 mm, actual settling 140 mm. Settling still continues, no damage.

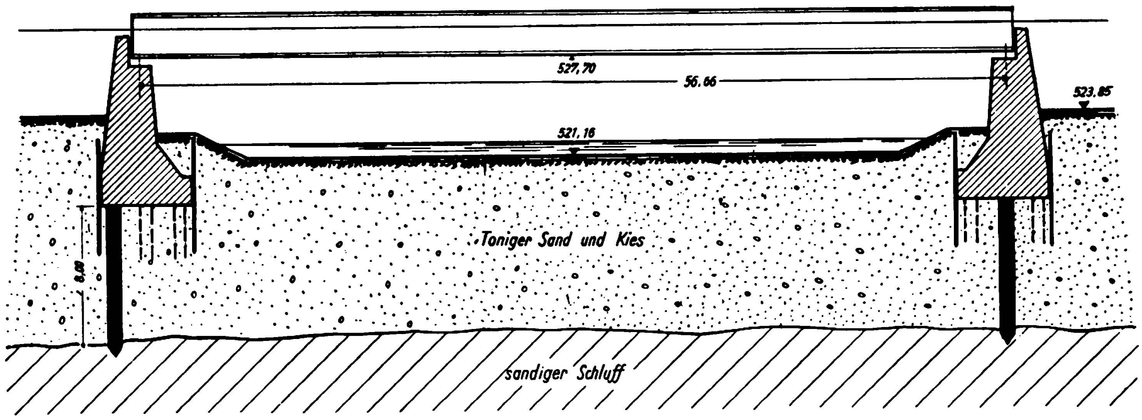

Fig. 11.

6. Work at km 40.584, Stuttgart Office. Vaulted culvert, spread foundations on 1.30 m sand, under which soft clayey silt (valley loam), natural water content 43%, flow limit 54%, rolling limit 31%. Foundation pressure about 1.5 kg/cm². Completed December 1935, actual settling to April 1936 about 280 mm. Settling still continues.

7. Work No. 66, km 89.515, Königsberg Office. Two plate girders, each 16 m span. Spread foundations 1.4 kg/cm² on alternating layers of compact and siltlike clay; compact clay: natural water content 35—37%, flow limit 57—67%, rolling limit 24—26%; siltlike clay: natural water content 25—30%, flow limit 35—38%,

rolling limit 13—23%. Completed July 1935, actual settlings about 35 mm for abutments, 70 mm for piers, last measurement August 1935. Settling still continues.

8. Work No. 228, km 323.030, Hanover Office. Three-hinged arch, 14 m span, spread foundations on deep loess (fig. 24), foundation pressure 2.6 kg/cm², completed June 1935, settling to April 1936 about 40 mm. Settling stopping, no damage (fig. 3).

9. Work No. 229, km 323.538, Hanover Office. Three-hinged arch, 14 m span (fig. 4), foundation pressure 2.6 kg/cm², spread foundations partly on sandy loess. Completed August 1935, settling to April 1936, about 23 mm. Settling stopping, no damage.

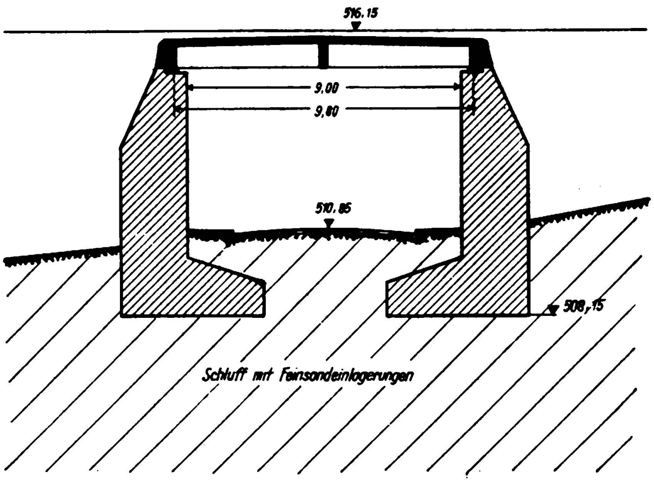

Fig. 12.

10. Work at km 89.255, Munich Office. Reinforced concrete 3-bay deck girder, central bay as Gerber girder, outer spans 8,40 m, inner 11.80 m (fig. 5). Floating pile foundation (Franki piles) about 10 m long, mean foundation pressure 1.1 kg/cm² below abutments, 1.4 kg/cm² below piers. Subsoil coarse sand and fine gravel, under which silt and siltlike clay (fig. 25). Silt: natural water content 33%, flow limit 36%, rolling limit 27%. Siltlike clay: natural water content 32%, flow limit 38%,

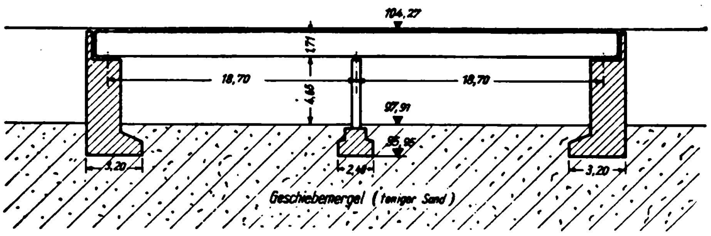

Fig. 13.

rolling limit 27%. Completed December 1935, predicted settling for abutments about 120 mm, for piers 90 mm, actual settlings to April 1936, for abutments about 125 mm, for piers about 60 mm. Settling still continues (fig. 33).

11. Work at km 77.695, Munich Office. Reinforced concrete 3-bay deck girder (fig. 6). Foundation: one abutment and one row of piers each on continous foundation slab, Franki piles 9 m long (floating pile foundation). Foundation pressure at its lowest edge about 1.1 kg/cm², subsoil consists of silt over 40 m deep, natural water content 34—64%, flow limit 35—72%, rolling limit 8—28%, permeability

3.7×10^{-5} to 1.3×10^{-4} cm/min. (for distribution of particles see fig. 26). Completed May 1936, predicted settling about 470 mm, actual settling to May 1936 about 500 mm. Settling still continues and damage is apparent (fig. 34).

12. Work at km 89.213, Munich Office (fig. 7). Reinforced concrete slab, 8.70 span, mean foundation pressure about 1.50 kg/cm², subsoil coarse sand and fine

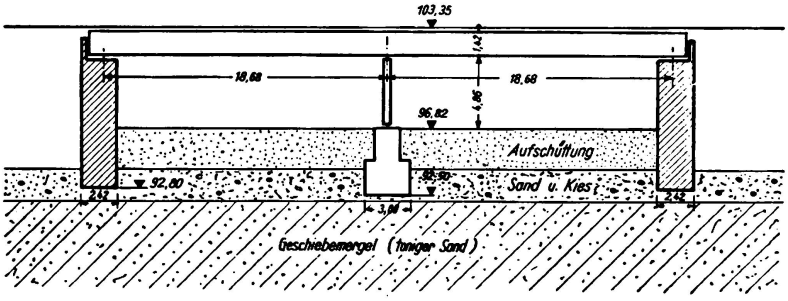

Fig. 14.

gravel, under which fine sand, under which silt and siltlike clay (fig. 27); pile foundations to upper edge of silt. Silt: natural water content 33—36%, flow limit 36%, rolling limit 27%, siltlike clay: natural water content 32%, flow limit 38%, rolling limit 27%. Completed December 1935, predicted settling about 200 mm, actual settling to May 1936 about 150 mm (fig. 35). No damage.

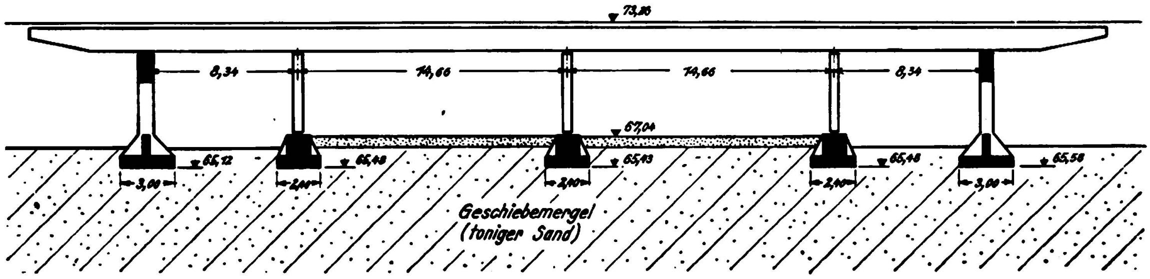

Fig. 15.

13. Work at km 78.246, Munich Office. Reinforced concrete deck girder, 13 m span (fig. 8), pile foundations (Franki) about 10 m long, mean foundation pressure 1.5 kg/cm², subsoil sand and gravel, under which fine and coarse sand, under which

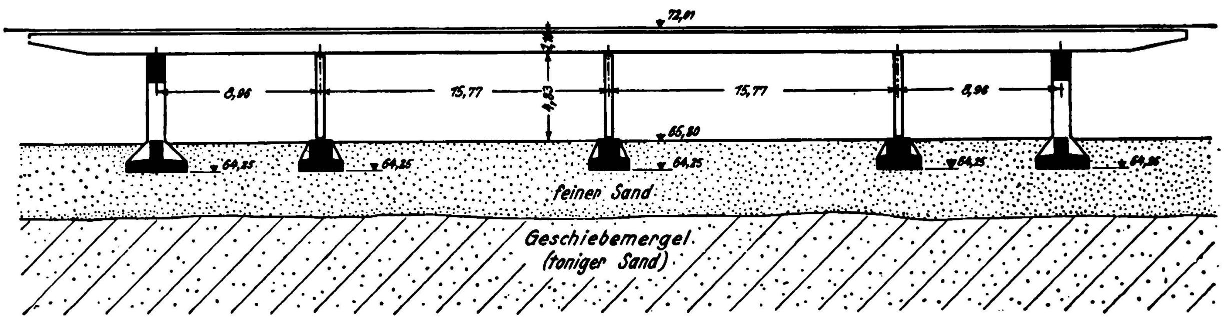

Fig. 16.

clayey silt (fig. 28): natural water content 19—32%, flow limit 31—39%, rolling limit 16—24%, permeability 2.6×10^{-7} to 1.1×10^{-6} cm/min. Completed August 1935, predicted settling about 250 mm, actual settling to end of March 1936 about 60 mm (fig. 36), no damage.

14. Work at km 86.455, Munich Office. Reinforced concrete deck girder with 13 m span (fig. 9). Abutments on Franki piles about 10 m long, mean foundation pressure 1.3 kg/cm², subsoil silt layers intercalated with fine sand to 20 m depth, under which compact marl (fig. 29). Silt: natural water content 32—54%, flow limit 32—51%, rolling limit 27—38%, permeability 1.1×10^{-6} to 4.0×10^{-5} cm/min. Completed October 1935, predicted settling about 350 mm, actual settling to May 1936 about 230 mm (fig. 37). Settling still continues, slight backward inclination of abutments (in consequence of embankment filling).

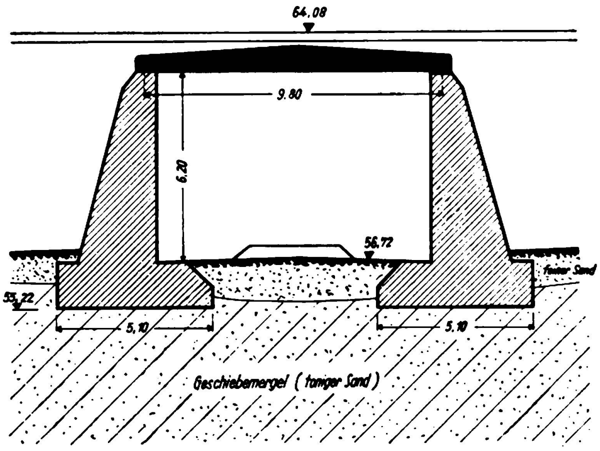

Fig. 17.

15. Work at km 61.863, Munich Office. Reinforced concrete deck girder with 11.1 m span (fig. 10), abutment foundations on common slab, pier foundation with wood piles about 8—11 m long, mean foundation pressure 1.0 kg/cm², subsoil silt with thin veins of sand, depth not ascertainable; silt: natural water content 24—32%, flow limit 30—33%, rolling limit 15—22%, permeability 2×10^{-6} cm/min. (for distribution of particles see fig. 30). Completed November 1935, predicted settling about 350 mm, actual settling to May 1936 200 mm (fig. 38), settling still continues, no damage.

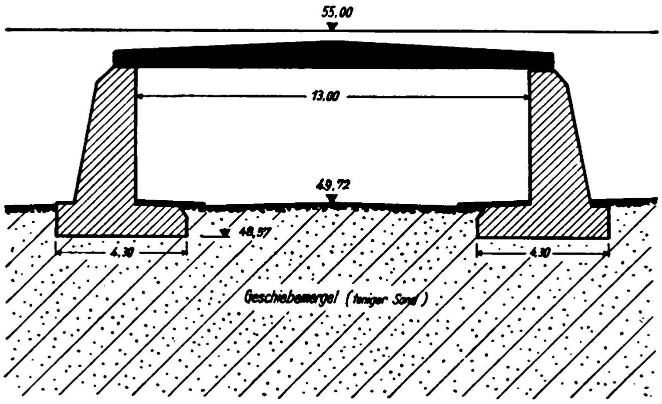

Fig. 18.

16. Work at km 88.695, Munich Office. Plate girder with 56.66 m span (fig. 11). Foundation of the abutments on wood piles about 8 m long, mean foundation pressure 2.0 kg/cm², subsoil clayey sand and gravel, under which sandy silt in parts very soft (fig. 31); natural water content 32—48%, flow limit 23—43%, rolling limit 22—41%, permeability 8×10^{-7} to 4×10^{-6} cm/min. Completed July 1936,

predicted settling of eastern abutment 900 mm of western abutment 500 mm, actual settlings average 300 mm (fig. 39), settling still continues, abutments have inclined backwards (in consequence of embankment filling).

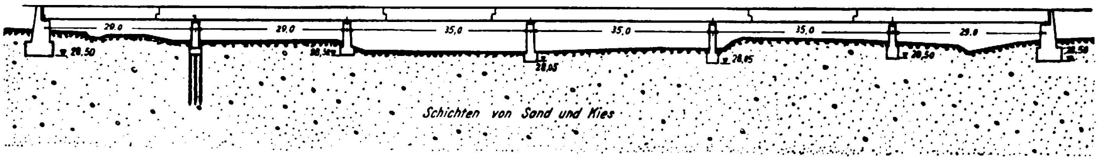

Fig. 19.

17. Work at km 65.179, Munich Office. Reinforced concrete deck girder of 9.80m span (fig. 12), spread foundations on silt (fig. 32) intercalated with fine sand to a great depth, mean foundation pressure 1.8 kg/cm². Completed July 1935, predicted settling about 350 mm, actual settling 280 mm to May 1936 (fig. 40), sett-

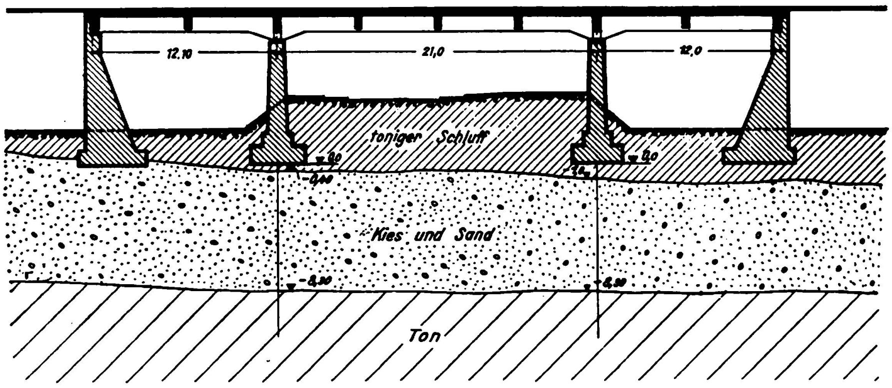

Fig. 20.

ling still continues, slight backward inclinations of the abutments and opening of the construction joints.

18. Work No. 32, km 43.8, Berlin Office. Two-bay girders of each 15.3 m span (fig. 13), spread foundations on drift-marl (sandy clay), natural water content 15%. Mean foundation pressure 2.5 kg/cm². Completed December 1935, predicted settling 80—100 mm, actual settling about 12 mm to December 1935, settling stopping, no damage.

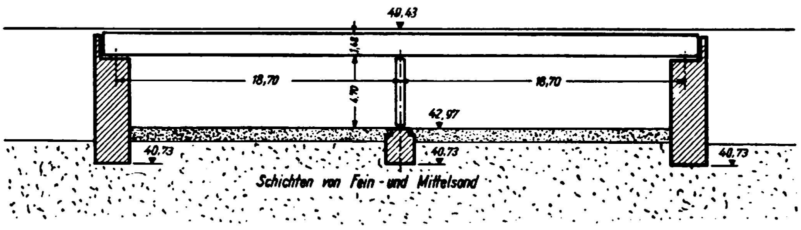

Fig. 21.

19. Work No. 33, km 44.6, Berlin Office. Two-bay girders of ecch 18.7 m span (fig. 14), spread foundations on thin sandy gravel bed, under which drift marl of great thickness. Mean foundation pressure 3.0 kg/cm². Completed March 1936, predicted settling about 10 mm, actual settling to March 1936 about 14 mm. Settling stopped, no damage.

20. Work No. 102, km 6.928, Berlin Office. Four-bay girder, total length 46 m (fig. 15). Spread foundations on drift marl: natural water content 12.4%. Mean foundation pressure 3.0 kg/cm². Completed November 1935, predicted settling about 20 mm, actual settling about 5 mm to January 1936. Settling stopped, no damage.

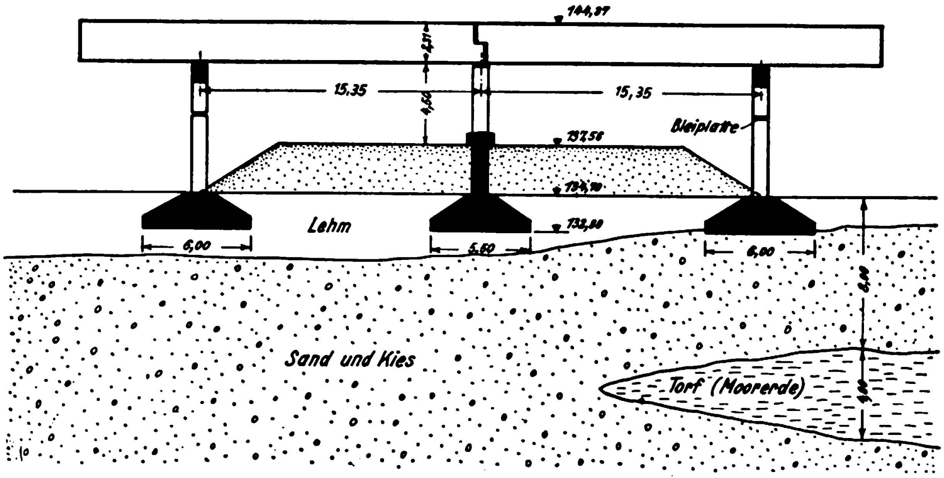

Fig. 22.

21. Work No. 104, km 9.628, Berlin Office. Four-bay girder, total length 49.5 m (fig. 16). Spread foundations on 3 m fine sand, under which drift marl: natural water content 12%, mean foundation pressure 3.0 kg/cm². Completed November 1935, predicted settling about 20 mm, actual settling to January 1936 about 5 mm, settling stopped, no damage.

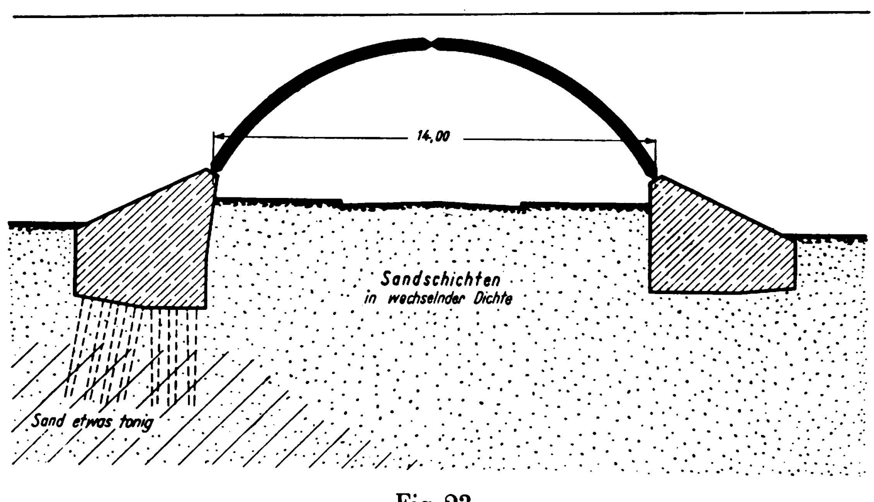

Fig. 23.

22. Work No. 111, km 16.553, Berlin Office. Deck girder of 9.8 m span (fig. 17)· Spread foundations on drift marl: natural water content 10.7%, mean foundation pressure 3 kg/cm². Completed November 1935, predicted settling about 20 mm, actual settling to January 1936 about 15 mm. Settling stopped, no damage.

23. Work No. 115, km 20.560, Berlin Office. Girder bridge of 13 m span (fig. 18). Spread foundations on drift marl: natural water content 14.7%, mean foundation

pressure 2.5 kg/cm². Completed July 1935, predicted settling about 60—80 mm, actual settling to January 1936 about 16 mm. Settling stopped, no damage.

24. Work No. 15, km 19.942, Königsberg Office. Four-bay girder, total length 55.8 m, spread foundations on drift marl, mean foundation pressure 2.5 kg/cm² for abutments and 3.0 kg/cm² for piers. Completed January 1935, actual settling to August 1935 about 5 mm. Settling stopped, no damage.

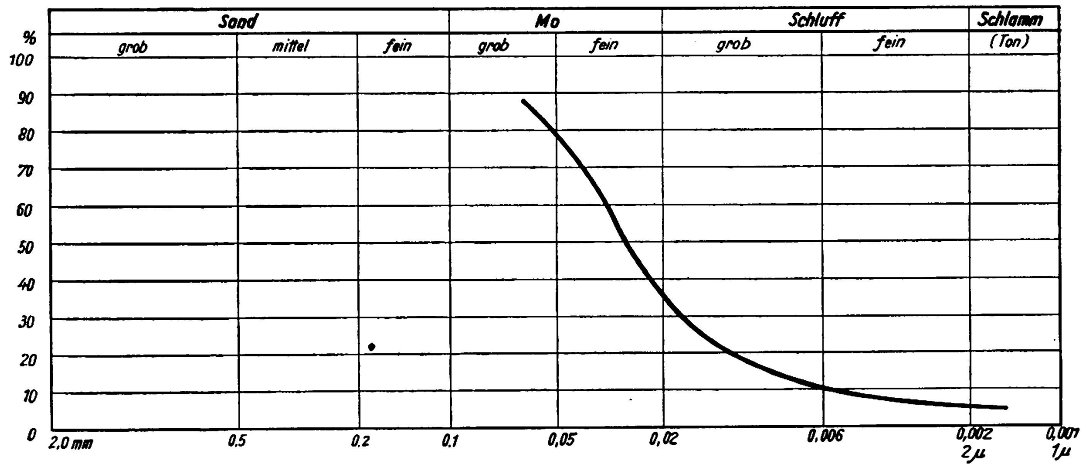

Fig. 24.

25. Work No. 16a, km 21.658, Königsberg Office. Girder bridge of 4.50 m span, spread foundations on drift marl, mean foundation pressure 2.5 kg/cm². Completed April 1935, actual settling about 15 mm. Settling stopped, no damage.

26. Work No. 157, km 52.555, Königsberg Office. Closed frames with 6.0 m span, spread foundation on 2—3 m sand layer, under which drift marl to very great depth: natural water content 15—27%, flow limit 27—34%, rolling limit 18—20%.

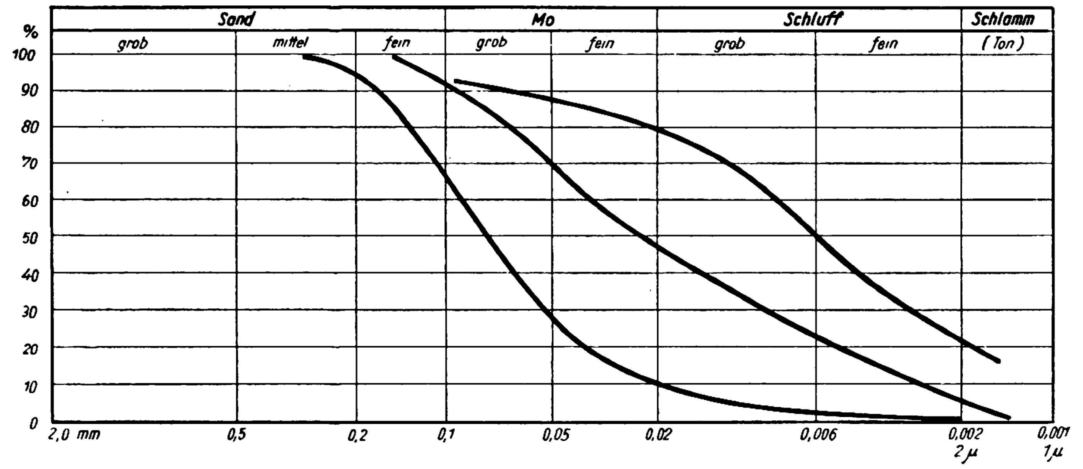

Fig. 25.

Mean foundation pressure 2 kg/cm². Completed August 1934, actual settling on average about 120 mm to August 1935. Settling stopped, steps formed at the construction joints (in consequence of inequalities in filling).

27. Work No. 14, km 19.400, Königsberg Office. Two-bay girder, spread foundations on drift marl with intercalations of clayey fine sand, mean foundation pressure

2.5 kg/cm² for abutments, 3 kg/cm² for piers. Completed November 1934, actual settling to August 1935 about 12 mm. Settling stopped, no damage.

28. Work No. 13, km 18.6, Königsberg Office. Two-bay girders with each 14.3 m span, spread foundations on 1.50 m clayey fine sand, under which alternating layers of clayey fine sand and drift marl. Mean foundation pressure 2.5 kg/cm² for abut-

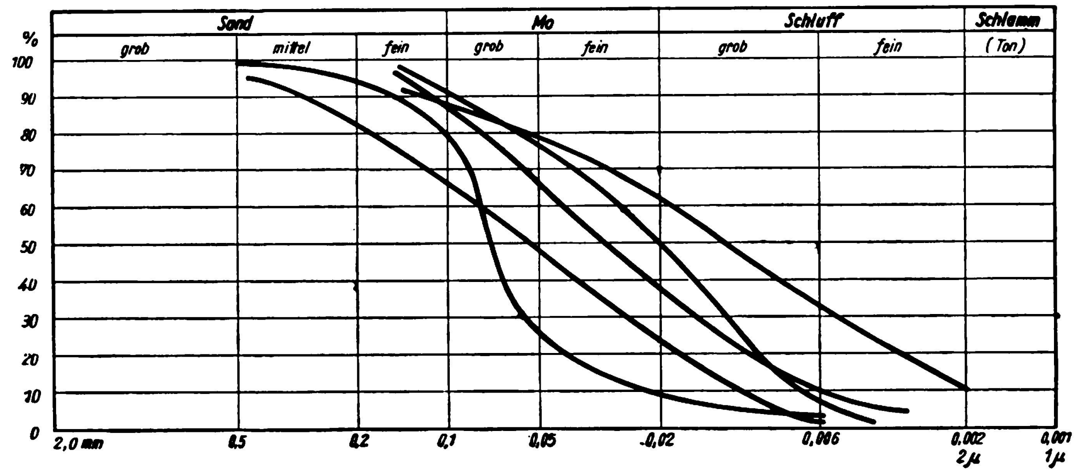

Fig. 26.

ments, 3.0 kg/cm² for piers. Completed November 1934, actual settling to August 1935 about 10 mm. Settling stopped, no damage.

29. 5 works without exact designation of position, Stettin Office. Spread foundations on drift marl, mean foundation pressure 2.8—3.0 kg/cm². No settling and no damage.

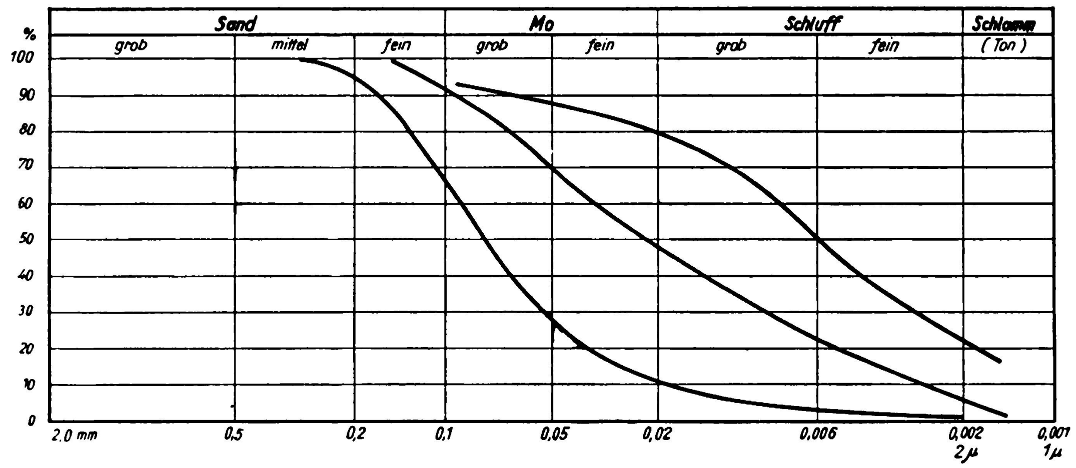

Fig. 27.

30. 9 two-bay deck girder bridges, Stettin Office. Spread foundations on drift marl, mean foundation pressure 2.5—4.0 kg/cm². No settling and no damage.

31. 3 two-bay deck girder bridges, Stettin Office. Spread foundations on 2—3 m clayey sand, under which drift marl mean foundation pressure 2.65 kg/cm²; no settling and no damage.

32. 3 two-bay deck girder bridges, Stettin Office. Spread foundations on 2—3 m

clayey sand, under which sand layers of great depth. Mean foundation pressure 2.2—2.5 kg/cm², actual settlings between 0 and 5 mm, no damage.

33. Work No. 8, km 12.63, Königsberg Office. Reinforced concrete frame of 15.4 m span on reinforced concrete piles 4—6 m long. Subsoil siltlike and clayey fine sand and gravel. Completed June 1935, actual settling to June 1935 about 10 mm. Settling stopped, no damage.

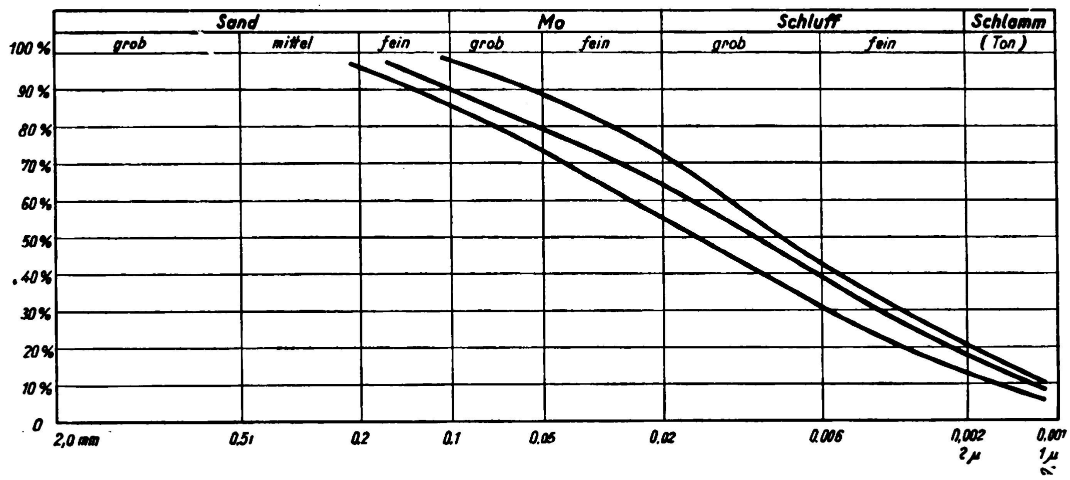

Fig. 28.

34. Work at km 69.122, Dresden Office. Continuous girder on 4 supports, spread foundations 2.5 kg/cm² on clayey sand: natural water content 21%, flow limit 35%, rolling limit 30%. Completed in August 1935, actual settling to August 1935, about 4 mm. Settling stopped, no damage.

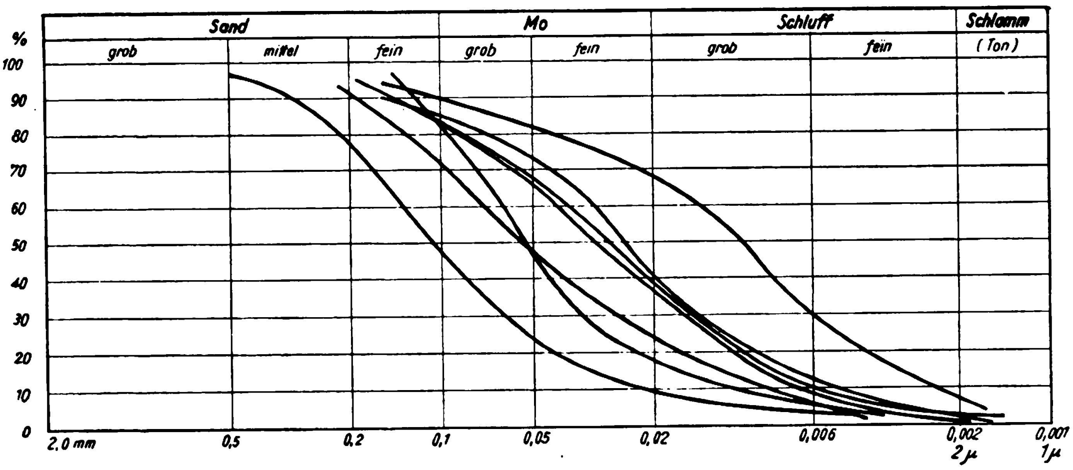

Fig. 29.

35. Work No. 155, km 48.262, Königsberg Office. Five-bay girder (plate-girder) 140 m long, 2 outer bays each 25 m and 3 central bays each 30 m span. Spread foundations, mean foundation pressure 2 kg/cm² for abutments and 3 kg/cm² for central piers. Foundations of central piers constructed between sheet iron piling. Subsoil sand layers, in parts slightly clayey, in 10—14 m depth drift marl. Completed September 1934, actual settling about 5 mm. Settling stopped, no damage.

36. Work No. 337, km 408.0, Hanover Office. Gerber girder over 6 bays, total length 190 m (fig. 19), spread foundations on layers of sand and gravel, first left-hand pier on pile foundation, as there is local appearance of clay and peat. Mean foundation pressure at abutments 1.5—1.7 kg/cm², at piers 1.5—3.0 kg/cm². Completed March 1936, actual settlings of abutments 16 mm, of piers 15 mm, of the first lefthand pier 19 mm. Settling stopped, no damage.

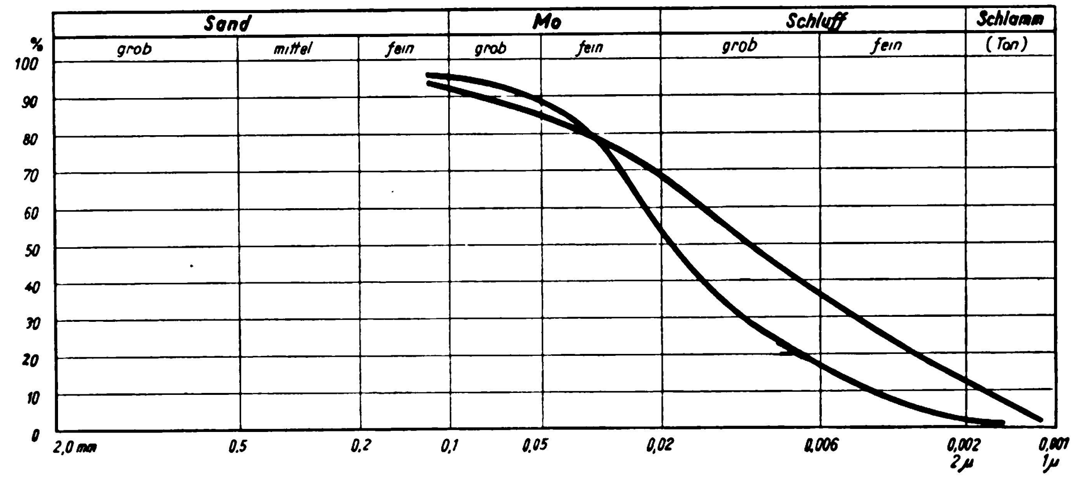

Fig. 30.

37. Work No. 252, km 334.7, Hanover Office. Three-bay deck girder, outer bays each 12 m, central bay 21 m span. Subsoil gravel and sand to a great depth, under which clay (fig. 20), mean foundation pressure at abutments 1.4 kg/cm², at piers 1.5 kg/cm². Completed August 1935, actual settlings at western abutment between

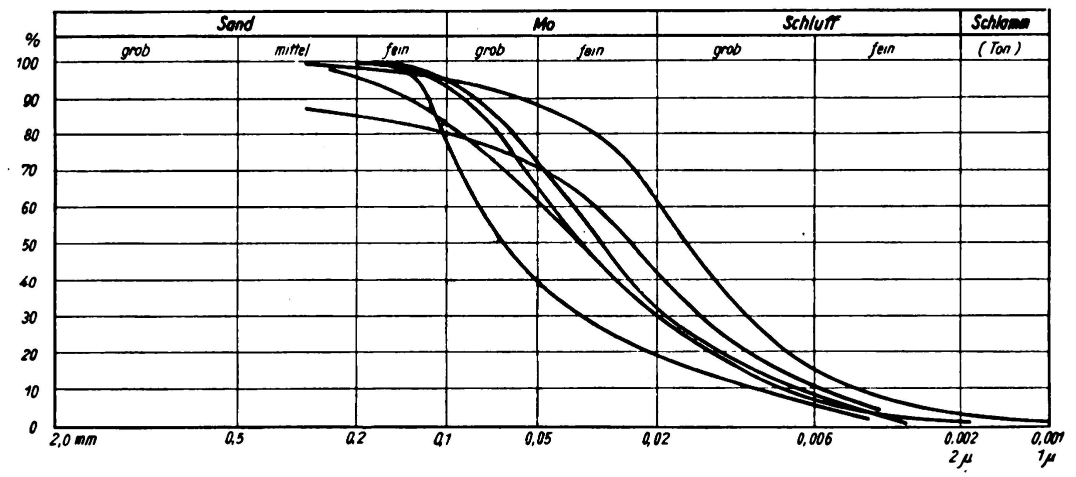

Fig. 31,

22 and 100 mm (roller bearing was lifted), at eastern abutment between 20 and 45 mm, at piers average 15 mm. Settling stopped, no damage (great settling of abutments conditioned by filling in behind the structures).

38. Work No. 18, km 19.431, Berlin Office. Two-bay girder with each 19.7 m span (fig. 21). Spread foundations on sand layers of various size of grain, mean foundation pressure 2.5 kg/cm². Completed February 1936, predicted settling about

10 mm, actual settling up to February 1936 about 10 mm. Settling stopped, no damage.

39. Work No. 7, km 4.863, Breslau Office. Two-bay girder with Gerber hinge over the central pier, each 15.35 m span (fig. 22), spread foundations on loam and deep sand and gravel, peat under the righthand outer pier at a great depth. Mean foundation pressure at outer piers 1.5 kg/cm², at central pier 2.0 kg/cm². Completed October 1934, outer piers turned outwardly on the average of 45 mm (March 1935), righthand outer pier also settled about 30 mm. Settling stopped, no damage.

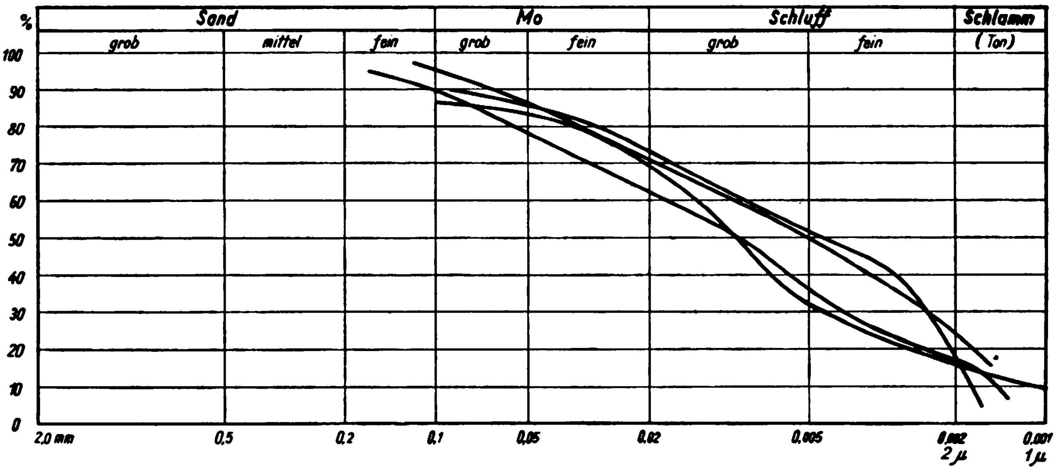

Fig. 32.

40. 13 girder bridges, Stettin Office. Spread foundations on partly very fine sand up to 12 m deep, mean foundation pressure 2.5 kg/cm². No settling and no damage.

41. Work No. 79, km 241.380, Hanover Office. Three-hinged arch of 14 m span, mean foundation pressure 2.7 kg/cm² (fig. 23). Subsoil sand layers of varying density, under the lefthand abutment somewhat clayey, therefore foundation on piles

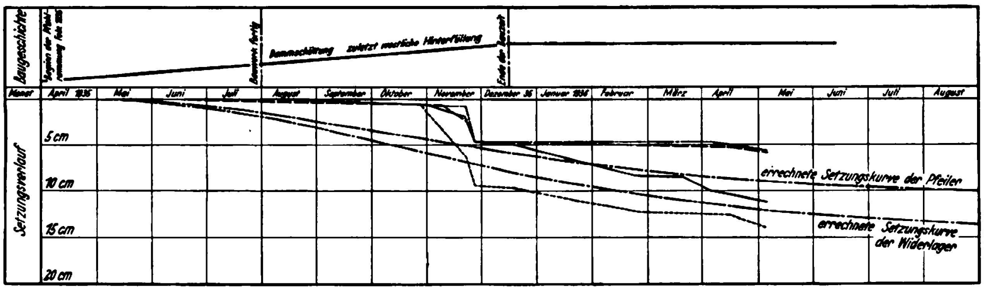

Fig. 33.

there. Completed April 1935, actual settlings western abutment 4 mm, eastern abutment (lefthand) 15 mm to March 1936. Settling stopped, the northern arch shows signs of cracks.

42. Work at km 7.167, Frankfurt-on-Main Office. Reinforced concrete frame with 19.55 m span, reinforced concrete rammed piles 10—11 m long, subsoil 5—10 m sand-gravel, under which stiff clay (in part sandy), mean foundation pressure 2.2 kg/cm². No settling and no damage.

43. Work at km 7.292, Frankfurt-on-Main Office. Reinforced concrete three-bay girder, central bay with suspended girder of 31.2 m span, side bays each 8.6 m.

Mean foundation pressure 2.1 kg/cm², side bays designed as frames with continuous slab between sheet piling. Subsoil 5—10 m sand-gravel, under which stiff clay (in part sandy), no settling and no damage.

44. Work at km 6.849, Frankfurt-on-Main Office. Reinforced concrete frame with

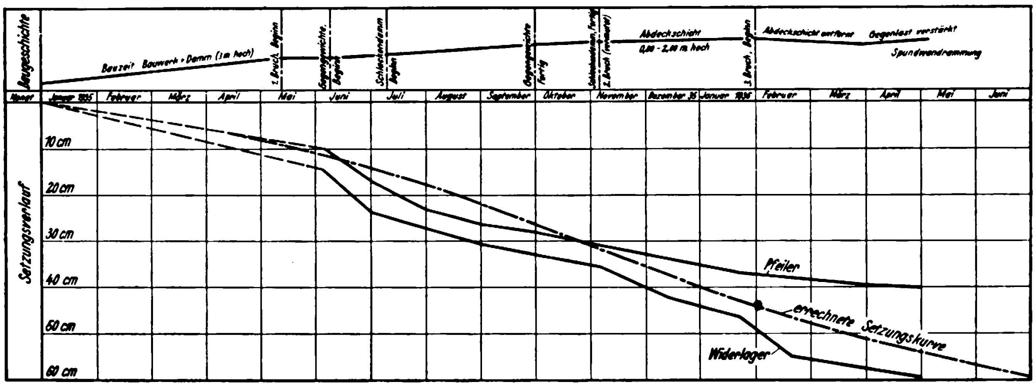

Fig. 34.

12.6 m span, spread foundations on 4—5 m sand-gravel, under which stiff clay (in part sandy) of great thickness: natural water content 15—21%, flow limit 25—50%, rolling limit 9—15%. Mean foundation pressure 2.2 kg/cm². No settling and no damage.

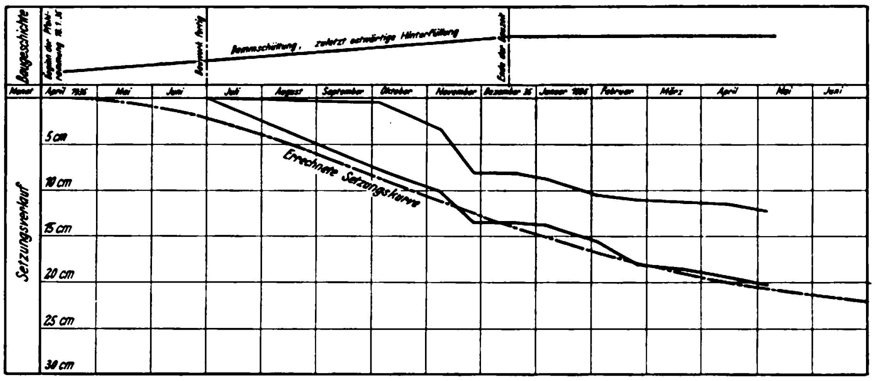

Fig. 35.

IV. Summary and conclusions.

In order to make things clearer, the essential data for a comprehensive judgement of the separate works are given in tabular form (tables 1—4). The soils in question may be practically classified in four groups, — clay and loess, silt, drift marl, sand and gravel (in part clayey). When the average settlings corresponding to these four groups are compared (table 5), — the separate values being, for the

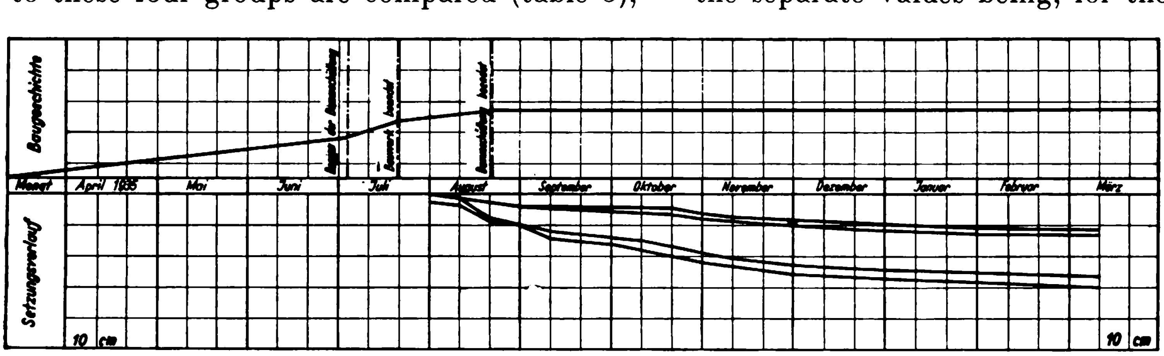

Fig. 36.

sake of simplicity, referred with the help of the theoretical settling curves quite roughly to the moment in which the greatest part of the movements is effected, — here also, in spite of the unequal influence, a number of factors such as thickness of layers and foundation pressure are found to bear a certain relation to each other. In order to prevent misunderstandings, however, it is necessary to call particular

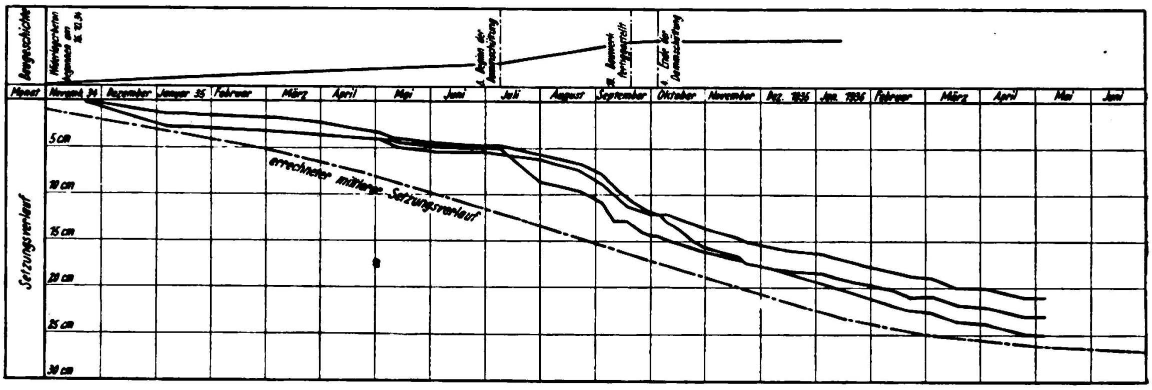

Fig. 37.

attention to the fact that the comparisons made in Table 5, and consequently also the conclusions deduced from them, refer solely to soil conditions found in Germany.

Of the 72 works on which observations have been made, about half rest on drift marl and about one third on sand-gravel beds of considerable thickness. As can

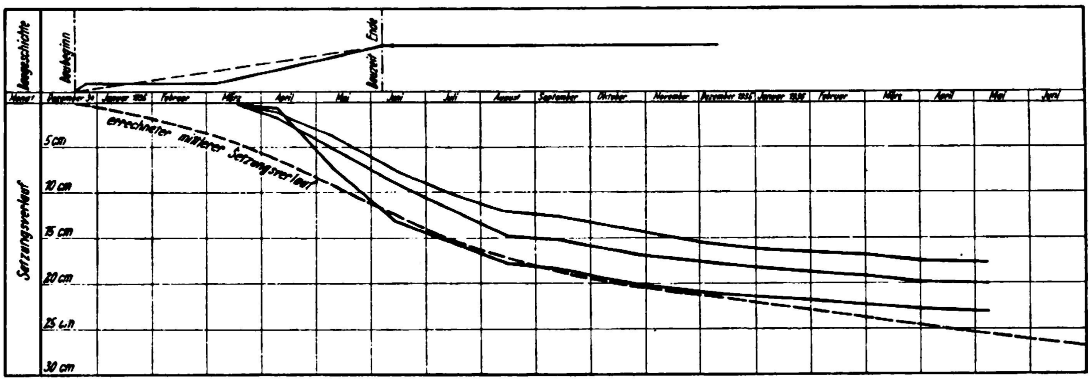

Fig. 38.

be seen from Table 5, the settlings amounted to 0—20 and 0—10 mm respectively for the two groups of soil mentioned. Control calculations have later shown that the factor of safety against the abutments and piers breaking through the foundation ground, with the maximum foundation pressures of 4.0 and 3.0 kg/cm² respectively, lies between 4 and 7. The slight settlings, together with the high factors of safety, would justify higher specific foundation pressures being adopted on beds of drift marl or sand-gravel. Assuming foundation pressures of 6 and 5 kg/cm², the factors of safety would still be 2 and 3 respectively, with only an inconsiderable increase in the settlings. Uniform settling with the adoption of considerably higher figures does not cause any damage; this is proved by the works built on clayey soils, in which settlings up to 200 m could be observed within a comparatively short time. Where damage has occurred, as for example outward inclination of the abut-

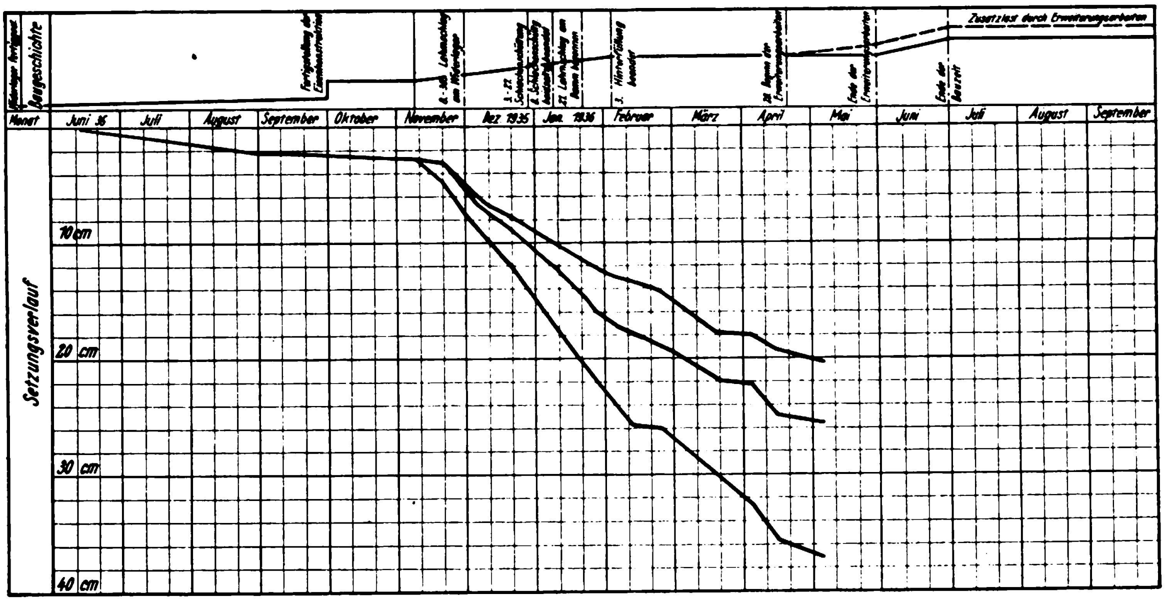

Fig. 39.

ments, it is without exception confined to cases where the embankment filling has been effected only after completion of the structure, or where the space to be filled between the abutment and embankment had been made very large (broad). The same holds essentially also for works resting on soft beds of silt, in so far as they are not caused to suffer through slides and irruptions of adjacent masses of earth in the embankment.

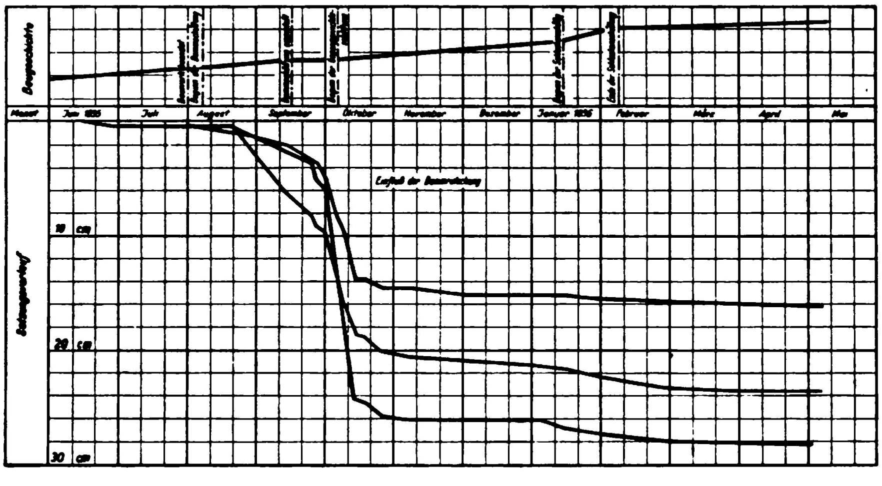

Fig. 40.

The greater part of the works is on spread foundations. Foundations on piles are confined cases where irregularities in settling were to be expected because of the irregular structure of the underground layers, or where the foundations had to be laid on soft siltlike layers.

As essential results of the present report, the following points deserve to be particularly noted: —

1. drift marl and sand-gravel beds of great thickness permit of higher loading than has hitherto been usual.
2. Embankment filling should be effected as soon as possible in order to prevent any irregular movements of the structure. The spaces to be filled in with earth behind the abutments after the structure has been completed should be kept as small as possible, when the structure rests on beds that are soft and not very permeable.

Table 1.

No.	Foundation	Mean foundation pressure kg/cm²	Principal subsoil layer	Completed	Predicted settling in mm	Observed settling in mm	Remarks
1	Spread	1.4	Clay, stiff	June 1935	—	Abutm. 54 pier 56 Apr. 1936	Still settling
2	Spread	2.4	Clay, stiff	Dec. 1935	—	Pier 52 Mar 1936	Still settling
3	Spread	Abutm. 1.5 pier 1,0	Siltlike clay, soft	Aug. 1935	Abutm. 150 pier 60	Abutm. 46 pier 25	Settling stopped
4	Spread	2.75	Clayey silt, soft	Feb. 1936	95	Av. 50 Apr. 1936	Settling stopped
5	Spread	1.1	Sandy clay	Nov. 1935	2,20	Av. 140 Apr. 1936	Still settling
6	Spread	1.5	Clayey silt, soft	Dec. 1935	—	Av. 280 Apr. 1936	Still settling
7	Spread	1.4	Compact clay and silt like Clay	July 1935	—	Abutm. 35 pier 70 Aug. 1935	Still settling
8	Spread	2.6	Loess	June 1935	—	Av. 40 Apr. 1936	Settling stopping
9	Spread	2.6	Loess, sandy	Aug. 1935	—	23 Apr. 1936	Settling stopping
10	Piles	Abutm. 1.1 pier 1.4	Silt, siltlike clay. soft	Dec. 1935	Abutm. 120 pier 90	Abutm. 125 pier 60 Apr. 1936	Still settling

Table 2.

No.	Foundation	Mean foundation pressure kg/cm²	Principal subsoil layer	Completed	Predicted settling in mm	Observed settling in mm	Remarks
11	Piles floating	1.1	Silt, soft	May 1936	470	Av. 500 May 1936	Still settling
12	Piles, floating	1.5	Silt, siltlike clay soft	Dec. 1935	200	Av. 150 May 1936	Still settling
13	Piles, floating	1.5	Silt, soft	Aug. 1935	250	Av. 60 Mar. 1936	Still settling
14	Piles, floating	1.3	Silt, soft	Oct. 1935	350	Av. 230 May 1936	Still settling
15	Piles, floating	1.0	Silt, soft	Nov. 1935	350	Av. 200 May 1936	Still settling
16	Piles, floating	2.0	Silt, soft	July 1936	east abut. 900, west abut. 500	Av. 300 Mai 1936	Still settling
17	Spread	1.8	Silt	July 1935	350	Av. 280 May 1936	Still settling
18	Spread	2.5	drift marl, sandy clay	Dec. 1935	80—100	12 Dec. 1935	Settling stopped
19	Spread	3.0	drift marl, sandy clay	Mar. 1936	10	Av. 14 Mar. 1936	Settling stopped
20	Spread	3.0	drift marl, sandy clay	Nov. 1935	40—60	Av. 7 Jan. 1936	Settling stopped
21	Spread	3.0	drift marl, sandy clay	Nov. 1935	20	Av. 5 Jan. 1936	Settling stopped
22	Spread	3.0	drift marl, sandy clay	Nov. 1935	20	Av. 15 Jan. 1936	Settling stopped

Table 3.

No.	Foundation	Mean foundation pressure kg cm²	Principal subsoil layer	Completed	Predicted settling in mm	Observed settling in mm	Remarks
23	Spread	2.5	drift marl, sandy clay	July 1935	60—80	Av. 16 Jan. 1936	Settling stopped
24	Spread	Abutm. 2.5 pier 3.0	drift marl, sandy clay	Jan. 1935	—	Av. 5 Aug. 1935	Settling stopped
25	Spread	2.5	drift marl, sandy clay	Apr. 1935	—	Av. 15 Aug. 1935	Settling stopped
26	Spread	2.0	drift marl, sandy clay	Aug. 1934	—	Av. 120 Aug. 1935	Settling stopped
27	Spread	Abutm. 2.5 pier 3.0	drift marl, clayey fine sand	Nov. 1934	—	Av. 12 Aug. 1935	Settling stopped
28	Spread	Abutm. 2.5 pier 3.0	Clay, sand, drift marl	Nov. 1934	—	Av. 10 Aug. 1935	Settling stopped
29	Spread	3.0	drift marl, sandy clay	—	—	none	—
30	Spread	2.5—4.0	drift marl, sandy clay	—	—	none	—
31	Spread	2.65	drift marl, sandy clay	—	—	none	—
32	Spread	2.2—2.5	Loamy sand	—	—	0—5	Settling stopped
33	Spread	3.0	Sand, clayey silt	June 1935	—	Av. 10 June 1935	Settling stopped
34	Spread	2.5	Clayey sand	Aug. 1935	—	Av. 4 Aug. 1935	Settling stopped

Table 4.

No.	Foundation	Mean foundation pressure kg/cm²	Principal subsoil layer	Completed	Predicted settling in mm	Observed settling in mm	Remarks
35	Spread	Abutm. 2.0 pier 3.0	Sand, slightly clayey	Sept. 1934	—	Av. 5 Feb. 1935	Settling stopped
36	Spread	Abutm. 1.5 — 1.7, pier 1.5—3.0	Sand-gravel, pier I, clay, peat	Mar. 1936	—	Abutm. 16 pier 15 pier I, 19 Apr. 1936	Settling stoppel
37	Spread	Abutm. 1.4 pier 1.5	Sand-gravel, part clayey	Aug. 1935	—	Abutm. 20 to 100 pier 15 Apr. 1936	Settling stopped
38	Spread	2.5	Sand	Feb. 1936	10	10 Febr. 1936	Settling stopped
39	Spread	Outer pier 1.5, centr. pier 2.0	Thin loam layer, sand, gravel	Oct. 1934	—	Horiz. 45 Mar. 1935	Settling stopped
40	Spread	2.5	Sand	—	—	none	—
41	Spread west abutm., piles east abutm.	2.7	Sand, part clayey	April 1935	—	West abutm. 4 east abutm. 15 Mar. 1936	Settling stopped
42	Piles	2.1	Sand-gravel, clay	—	—	none	—
43	Spread with sheet piling	2.2	Sand-gravel, clay	—	—	none	—
44	Spread	2.2	Sand-gravel, clay	—	—	none	—

Table 5.

Number of structures	Soil group	Mean foundation pressure in mm	Settling in mm
9	Silt	1,1—2,0	200—1000
8 (11)	Clay, loess, loam etc.	1,1—2,6	50—200
81	drift marl, sandy and gravelly clay	2,5—4,0	0—20
24 (21)	Sand, gravel	1,5—3,0	0—10

Vocabulary for illustration texts:

Deutsch	English
A	
Abdeckschicht entfernt	top layer removed
Abdeckschicht ... hoch	top layer ... high
Aufschüttung	filling
B	
Baubeginn	beginning of construction
Baugeschichte	construction records
Bauwerk beendet / Bauwerk fertiggestellt	structure completed
Bauzeit, Bauwerk und Damm (3 m hoch)	construction time, structure and dam (3 m high)
Beginn der Dammschüttung	commencement of dam filling
Beginn der Pfahlrammung Februar 1935	start of pile driving Feb. 1935
Beginn der Erweiterungsarbeiten	commencement of extension work
Beginn der Gegengewichtsschüttung	commencement of ballasting
Beginn der Schlackenschüttung	commencement of cinder depositing
Bruch, Beginn	fracture, start
Bruch (vermutet)	fracture (suspected)
D	
Dammschüttung, zuletzt westliche Hinterfüllung	dam filling, western back filling last
Dammschüttung, zuletzt ostwärtige Hinterfüllung	dam filling, eastern back filling last
Dammschüttung beendet	dam filling completed
Dammschüttung eingestellt	dam filling interrupted

E	
Einfluß der Dammrutschung	influence of dam slipping
Ende der Bauzeit	end of construction time
Ende der Dammschüttung	completion of dam filling
Ende der Erweiterungsarbeiten	completion of extension work
Ende der Schlackenschüttung	completion of cinder deposits
Errechneter mittlerer Setzungsverlauf	calculated average values of subsidence
Errechnete Setzungskurve der Pfeiler	calculated curve of pier subsidence
Errechnete Setzungskurve der Widerlager	calculated curve of abutment subsidence
F	
fein	fine
Feinsand	fine sand
Fertigstellung der Eisenkonstruktion	completion of steel structure
G	
Gegengewichte, Beginn	counter weights, start
Gegengewichte fertig	counter weights, finished
Gegenlast verstärkt	counter weights increased (or strengthened)
Gelenk	hinge
Geschiebemergel (toniger Sand)	marl (clayey sand)
Grob	coarse (rough)
Grobsand und Feinkies	coarse sand and fine shingle
H	
Holzpfähle 8 m lang	wooden piles 8 m long
Hinterfüllung beendet	back filling completed
K	
Kies	shingle
L	
Lehm	clay
Lehmschlag am Widerlager	clay deposit at abutment
Lehmschlag am Damm begonnen	clay deposit for dam started
Löß, etwas sandig	loess, slightly sandy
Lößlehm	loess-clay
M	
Monat	month
mittel	average (or mean)
Mo (= Moorerde)	Mo = moor soil
P	
Pfeiler	pier
S	
Sand, etwas tonig	sand slightly clayey
Sandschichten in wechselnder Dichte	layers of sand in variable thickness
Sandschüttung	sand filling
Sand	sand
sandiger Schluff	sandy silt
Setzungsverlauf	run of subsidence
Schichten von Fein- und Mittelsand	layers of fine and medium grain sand
Schichten von Sand und Kies	layers of sand and shingle
Schlackendamm Beginn	cinder dam started
Schlackendamm fertig	cinder dam completed
Schlackenschüttung	cinder filling
Schlackenschüttung beidseitig beendet	cinder filling on both sides completed
Schlamm	mud
Schluff	silt
Schluff mit Feinsandeinlagerungen	silt mixed with fine sand
schluffiger Ton (weichplastisch)	sticky clay (plastic and soft)
steifer Ton, z. T. sandig	stiff clay partly sandy
Spundwandrammung	shut pile ramming

T

Ton	clay
toniger Sand und Kies	clayey sand and shingle
toniger Schluff	clayey silt
Torf (Moorerde)	peat

W

Widerlagerbeton begonnen am	concreting of abutment started on
Widerlager	abutment
Widerlager fertiggestellt	abutment completed

Z

Zusatzlast durch Erweiterungsarbeiten	supplementary load due to extensions.

Summary.

The author describes the soil conditions for a large number of new structures which were built in connection with the new Reich Motor Car Road system. He compiled the measured subsidences and compares the measured values with those predicted.