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Harms, F.; Berz, R.

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EXCAVATION BRACING IN THE BERLIN METHOD OF SUBWAY CONSTRUCTION

BY

FRANZ HARMS AND RICHARD BERZ

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TRANSLATED BY

D. A. SINCLAIR

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PREFACE

Since the beginning of construction of Canada's first subway, the Yonge Street Subway in Toronto (1949-1953), it has been the privilege of the Division of Building Research of the National Research Council to cooperate closely with the Toronto Transit Commission on a number of research problems in the field of soil mechanics, foundations, structures, geology, vibration and acoustics. In brief, the subway construction was used as a "research laboratory" so that experience gained in the course of design and construction of this important and difficult project might become available to other engineers and specialists in various fields. A number of research papers have evolved from this research activity.

The Division of Building Research has also been anxious to help in making available knowledge and literature from other countries to the Canadian engineers. It is in this sense that this translation of a German article on the highly developed excavation bracing systems used in the "cut-and-cover" method (or Berlin method) of subway construction is presented.

The paper was translated by Mr. D.A. Sinclair of the Translations Section of the National Research Council Library, to whom the Division of Building Research wish to record their thanks.

Ottawa,
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R.F. Legget,
Director

NATIONAL RESEARCH COUNCIL OF CANADA

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(Die Baugrubenaussteifung beim Bau von Untergrundbahnen nach der Berliner Bauweise)

Authors: Franz Harms and Richard Berz

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EXCAVATION BRACING IN THE BERLIN METHOD OF SUBWAY CONSTRUCTION

1. Introduction

All Berlin subways (underground railways) have been built by the so-called Berlin method of tunnel construction. In London a layer of clay, which begins at a depth of 6 to 9 metres, made it possible to use the shield method, and in Paris the presence of a hard gravel and marl layer permitted the use of the Belgian method of tunnel construction (underpinning method with top and bottom heading). In Berlin, on the other hand, attempts to avoid open excavations and to apply underground mining methods have been unsuccessful because of the sand and gravel beds.

The Berlin method has proved successful both here and abroad in almost sixty years of application, if we disregard the accident at Friedrich-Ebert-Strasse (formerly Hermann-Göring-Strasse), which happened only because of a faulty execution(1). The most important features of the Berlin method are:

1. Excavation of an open cut which, along main streets, is completely or partially covered shortly after the start of excavation work by a temporary road deck for resumption of surface traffic;
2. Support of the sides of the excavation with timbered walls;
3. Dewatering of the excavation by lowering the ground water table.

Since its first application on the Kleist- and Tauentzienstrasse the Berlin method has undergone many modifications. As applied today it is described in the "Richtlinien für die Festigkeitsberechnung und bauliche Durchbildung der Baugrubenaussteifung und-abdeckung für Tunnelbauten der Städtischen Schnellbahnen" (Guides to the design calculations and construction details of the excavation bracing and temporary decking for the tunnel structures of urban rapid transit systems,) hereafter referred to as RB(2) for short, which were drawn up by the Senator for Construction and

Housing.

In recent times subway construction has changed considerably by the use of all sorts of heavy equipment and machines. This incidentally explains the effort made in the new "Guides" (RB) to reduce to a minimum the number of bracing layers constricting the excavation cross-section and thus to provide only two bracing layers over the cross-sectional area of the tunnel. In addition to this the struts are to be such that the excavation for the normal double-track tunnel, including the widening at the curves, can still be constructed without a central support. The criterion for this is to be found in the head support of the struts.

Of fundamental importance in the further development of excavation bracing technique was the new concept that had been formed of the effect of the earth pressure on the excavation walls[3,5]. Numerous tests and measurements carried out on excavation walls from 1934 to 1938 revealed that Coulomb's triangular earth pressure diagram, which has hitherto been used as a basis for dimensioning, leads to incorrect results. The shore pressures in the upper part of the excavation are underdesigned, while in the lower part they are considerably overdesigned. The simplified, but fairly accurate assumption of an earth pressure diagram having the form of a rectangle equal in area to Coulomb's triangle results in tolerable shore dimensions with fewer shores and increased length.

2. Load Assumptions

2.1 Unit weights of building materials

Steel and steel castings	7.85 t*/m^3
(Gray) cast iron	7.25 t/m^3
Brick masonry	1.8 t/m^3
Sand and gravel (moist)	1.8 t/m^3
Sand and gravel (wet)	2.0 t/m^3

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* Translator's Note: t = metric ton

The unit weights of various kinds of lumber, according to the values laid down for bridges, are as follows:

Spruce and fir, air dry 550 kg/m³, wet 700 kg/m³;
Pine and larch, air dry 600 kg/m³, wet 750 kg/m³;
Oak and beech, air dry 800 kg/m³, wet 1000 kg/m³.

The unit weights given include allowances for small hardware (nails and screws), hardwood parts, and paint or impregnation as well as dirt.

2.2 Earth pressure

The specifications on load assumptions for structures (DIN 1055, sheet 1.3, edition of June 1940) provide for an angle of internal friction of $\rho = 30°$ for the calculation of the earth pressure in the case of moist sand and gravel. This value is based on the assumption of a cohesionless material in which the angle of internal friction agrees with the angle of repose.

From experience gained in the work on the Berlin subways, and considering the temporary use of the bracing, it is possible to depart from DIN 1055 and take an agle of $\rho = 37°$ as the angle of internal friction of moist sand.

This value takes the cohesion partly into account.

Thus, for moist sand

Unit weight	$\gamma = 1.8\ t/m^3$
Angle of internal friction	$\rho = 37°$
Angle of friction at the wall	$\delta = 0°$
Earth pressure coefficient	$\lambda_a = \tan^2(45° - \frac{\rho}{2}) = 0.25.$

For other types of soil corresponding values should be used.

The former earth pressure triangle is to be replaced by an earth pressure rectangle of equal area. The assumption of the rectangular loads in the lower part of the excavation results in a value of which according to on-the-spot measurements only about 70% is actually present. This difference makes it possible to neglect even a theoretically higher building pressure, which is approximately 60° within the range of the slide angle.

3. Principles of Calculation

Besides the "Guides" (RB), the following also apply insofar as they do not conflict with the RB:

1. Grundlagen für die Festikeitsberechnung des Tunnelbause der Städtischen Schnellbahnen (Principles of design calculation for tunnel construction of urban rapid transit systems), referred to as BT for short(6).
2. DIN, 1050, 1052, 1073, 1074, 4074, 4420.
3. Berechnungsgrundlagen für stählerne Eisenbahnbrücken (Principles of calculation for steel railway bridges), referred to as BE for short; published by Deutsche Bundesbah, April, 1955.
4. Strassenverkehrsordnung (StVO).
   Bau- und Betriebsvorschriften (Street traffic regulation, section on construction and operation).
5. Verordnung über den Bau und Betrieb der Strassenbahnen (BOStrab) (Regulation concerning the building and operation of street railways), with amendments of the 14.8.1953(7).

The guides (RB) are based on a different set of assumptions from the specifications for bridges. In the first place the wooden planking between I-beams demands that special consideration be given to concentrated loads, and secondly the construction methods result in the concentrated loading of the I-beams, in contrast to the load reduction that is permissible in the case of bridges. The loadings are predominantly single beam loadings or group loadings of deck beams, spaced 2 m supported by girders 6 m long.

3.1 Standard loads

According to the StVO (road traffic regulation) the loading of the excavation deck is determined from two standard vehicles chosen in accordance with the admissible maximum loads carried and the heavy trucks constructed for these by the motor industry (Fig. 1 and 2).

Since a change of loads according to the StVO comes into effect only on the 1 July 1960, the above assumptions hold for the time being. If the tramway has its own right-of-way the standard tramway loads (Fig. 3) can be applied, but these become invalid if the tramway lanes can be used by heavy trucks as well. The division into main, auxiliary and outside lanes (Fig. 4 to 7) is determined on the basis of stationary and moving vehicles for a normal mixed traffic of heavy and light vehicles.

Fig. 4 and 5 show the way in which the vehicles are grouped so as to arrive at the load assumptions for calculating the road deck beams. Fig. 6 and 7 show the arrangement for calculating the central beams.

3.2 Vibration coefficients

The vibration coefficients are included in the standard loads. For the main lanes they are $\varphi = 1.4$ for the road-deck beams and $\varphi = 1.2$ for the beams.

3.3 Substitute loads

The loads of the StVO do not exceed a suitable uniformly distributed load (substitute load) of $p = 1.1$ t/m^2. In view of the BVG (Berliner Verkehrs-Gesellschaft) vehicles also present in the traffic of the city, the uniformly distributed load applied in front of, behind and beside the vehicles (Fig. 4 to 7) is 0.7 t/m^2 plus the appropriate vibration coefficients. Generally speaking a traffic of heavier special purpose vehicles in the vicinity of the underground construction sites can be ruled out.

3.4 Braking loads

Braking and starting up loads for motor vehicles at the road surface level are to be taken as 1/20 the full load on the roadway at 0.7 t/m^2 without a vibration coefficient, taking into account the cross-bracings by which the traffic lines are divided, and which act as fixed points. However, they must be at least 0.3 times the weight of the stationary standard vehicles.

Where the tramway has its own right-of-way 1/10 the weight of all axles loading the superstructure in the vicinity of a fixed point should be applied at the level of the top of the rail. Tramways without their own right-of-way are to be treated as roadway surfaces.

3.5 Load distribution

In calculating the road deck surface the load distribution should be determined in accordance with DIN 1073 or 1074. For a 2 cm wear of the planking we obtain a distribution height of 3 + 18/2 = 12 cm. As a consequence of standardization of the traffic loading a wheel pressure of only $\varphi \times p = 1.4 \times 5 = 7$ t is involved. From a tire contact area of 0.48 m in one direction and 0.30 m in the other we get a load distribution of 0.72 m and 0.54 m, respectively. This yields a dead load for the wooden deck covering of 0.117 t/m in one direction and 0.097 t/m in the other.

The maximum moment from block load plus dead load is:

$M = 2.90$ t/m $\quad W_{required} = 2400\ cm^3 \quad W_{existing} = 4 \times 648 = 2592\ cm^3$

3.6 Pressure from buildings

If buildings of four to five storeys are present then regardless of their construction a soil pressure of 4 kg/cm^2 beneath the front walls, or a load of 40 t per running metre of building frontage should be assumed. To obtain maximum safety a load distribution below the foundation footing of 30° from the horizontal is assumed.

3.7 Permissible building materials

For decking and planking timber of quality class II, (sawn timber class A) is required. Used lumber and steel building materials may be employed after inspection for re-usability.

3.8 Safe stresses

The members require no special protective measures to ensure their long life, since they serve a temporary purpose. Hence, departing from DIN 1050, 1052 and 1073, a stress increase up to 20% is permissible.

3.8.1 Wood construction

For the decking, the plank walls, shores and other lumber, the following stresses are permissible:

Bending stress for coniferous wood permissible $\sigma_b = 100 + 20 = 120\ kg/cm^2$

Compressive stress parallel to grain	permissible $\sigma_d = 85 + 15 = 100$ kg/cm^2
Compressive stress at right angle to grain	
for coniferous wood	permissible $\sigma_d = 25 + 5 = 30$ kg/cm^2
for hardwood	permissible $\sigma_d = 40 + 8 = 48$ kg/cm^2

3.8.2 Steel structures

For calculating the decking, the outside and central pile beams, and other temporarily installed structural parts of St 37, the following stresses apply for bending, compression and tension stresses

permissible $\sigma = 1400 + 200 = 1600$ kg/cm^2

in exceptional cases permissible $\sigma = 1800$ kg/cm^2.

The deflection due to traffic loading must not exceed f = 1/400 of the beam span. In calculating the steel piles and road deck beams it is necessary to include a deduction for two screw holes of 21 or 25 mm diameter in order to make possible the installation of any bracings that may be necessary at any point without exceeding the permissible stress.

For screwed joints without fitting 4 D (formerly St 38.13) the following figures apply in accordance with the BE of 1st April, 1955:

Permissible shearing stress	$\tau_a = 1400$ kg/cm^2
Permissible bearing stress	$\sigma_1 = 2800$ kg/cm^2
Permissible tensile stress	$\sigma_z = 1000$ kg/cm^2

3.8.3 Road deck cross-beams

The cross-beams are to be calculated as beams on two supports. The number of joining screws required should be determined for 1.2 times the value of the total bearing pressure. If the cross-beams are used in place of braces for strengthening the excavation they should also be calculated for buckling.

3.8.4 Lower girders

Lower girders over the central pile beams normally have a length of 6.00 m and are also to be calculated as beams on two supports. If the distance from the interior tunnel roof surface to the top road surface is less than 2.25 m the sleepers are to be wedged in using I-beams; for IP-beams the smaller figure obtained from the lower beam height is sufficient.

3.8.5 Splicing of parts subject to bending stress

For splices of parts subject to bending stress the moment of inertia of the splices covering the joint must be at least equal to that of the parts joined. Each part must also be separately covered (see also under 4.4).

3.8.6 Connecting and splicing of cross-bracings

The diagonals of the cross-bracings are to be connected according to their net cross-section F_n, or according to their full cross-section divided by the buckling coefficient, F/ω. Diagonals which are subject to only small stresses and are designed according to practical considerations are to be spliced in accordance with the most practical principles.

4. Construction Details

4.1 Piles

For outer piles (up to 15 m in length) in normal sandy soil I-beams can be used. For outer piles of more than 15 m in length and in curves of less than 200 m radius with an excavation depth of more than 9.0 m, and also for all central piles, wide-flange profiles should be used.

The length of the piles depends on the depth of the excavation and the depth of penetration below the excavation floor.

	Depth of penetration in m	
	IP-beams	IP-beams
Excavation depth of 6 to 13 m		
Outer piles	1.50	1.80
Central piles	3.00	
Over 13 m or in unfavourable ground with $\rho \leq 25°$		
Outer piles	1.50	
Central piles	3.00	
in sump holes 1 m deeper		

Where only one layer of shores is used the pile should be calculated as a fixed-end beam. In general double the penetration depth is then required.

4.1.1 <u>Outer piles</u>

The outer piles should be placed as much as possible at equal intervals so that no rotation of the beams occurs due to unequal earth pressures. They should be driven in such a way that the shores can be installed in a straight line and at right angles to the tunnel axis or to the central piles. The reason for this is to keep the stress on the central piles due to the shoring forces to a minimum.

The standard outer pile spacing is 2.00 m. In curved tunnel sections this distance is to be maintained on the outside of the curve, in the case of intermediate walls at the centre of the wall. On the inside of the curve the interval should be reduced so that the shores can be installed in radial direction. The spacing of the central wall openings is to be chosen so that the shores will fall into the openings.

For the outer piles on straight stretches and in curves of more than 200 m diameter I-34 beams are to be used, except at station entrances, where I-28 to I-32 will suffice. In curves of less than 200 m diameter and an excavation depth of more than 9.00 m, IP-28 beams are to be provided. To ensure tightness of the construction the IP-beams should whenever possible be pulled again.

To determine the maximum permissible shore spacing in the vertical direction for the given pile section, the diagram for pile sections in Fig. 8 can be used. The use of the table is illustrated in the following examples.

1. Total shore pressure = 27.0 t

   vertical shore interval

   h_s = 3.80 m for three supports of the pile

   h_s = 1.80 m for four supports of the pile

   Section I-34

2. Total shore pressure = 16.0 t

h_s = 3.80 m for three supports of the pile

h_s = 3.75 m for four supports of the pile

Section I-26

1.1.2 Standard position central pile

The central piles (Fig. 9) should be driven at spacings three times the normal spacing of the outer piles, in any case 6.00 m apart and as far as possible not in a straight line between the outer piles. The shores or struts can then be carried past the central piles. In exceptional cases the central piles can be placed at 4.00 m intervals.

In case of extremely high loads or unfavourable soil conditions the compressive forces may no longer be supported safely by the wall friction of the pile ends in the soil. Then supplementary posts should be installed on either side of each central pile. Whether this post should be set up below the last or second-last shoring position, depending on the progress of excavation, is to be determined from case to case. In every case the effects of the load should be checked continuously.

Underpinning or the transfer of load of the central piles is carried out first at the tunnel floor and later at the tunnel ceiling. When the tunnel floor is concreted, conical holes of at least 1.50 × 1.50 m should be left at the central piles. After the concrete has set the pile should be supported on the finished tunnel floor to the side of the hole. The transfer of load from the central pile can be accomplished most simply in the manner of Fig. 11, rather than Fig. 10, omitting the two slanting braces. The pile is then cut about 20 cm below the waterproofing layer and about 20 cm below the upper edge. This piece is then removed, the protective coating, the waterproofing and the steel reinforcement are set in the hole, and after two steel angles have been fastened to the new pile end the hole is filled up with concrete (Fig. 10 and 11). The temporary support will be removed only when the central pile is dismantled. When the tunnel ceiling is constructed a hole is left wherever a central pile passes through. Each pile is then supported with steel sections resting on timber crib work constructed on the completely finished and waterproofed tunnel ceiling (Fig. 12 and 13). The central pile is cut off below the support, the lower part is removed and the ceiling is closed at this point, waterproofed and the protective coating applied. A block is concreted to the protective coating, the plan area of which is to be so dimensioned that the permissible compressive stress in the waterproofing of 1 kg/cm² will not be exceeded. The pile is to be protected against bonding of the concrete inside the concrete block so that the pile can later be easily lifted out.

The supporting and blocking of the piles should only proceed in small steps corresponding to the progress of backfilling.

4.1.3 <u>Central piles 2.00 m apart</u>

Where a wider floor span results from a particular track arrangement and the central piles are included in a wall they should be driven at intervals of 2 m.

4.1.4 <u>End walls</u>

End walls, i.e., vertical walls consisting of piles with planks between them should be avoided if possible. When they cannot be avoided the earth pressures, including that resulting from existing or expected vertical loads, against the end wall must be transferred to the outer walls and not to any central walls (Fig. 14).

4.2 <u>Planks and shores</u>

4.2.1 <u>Planks of the outside walls</u>

As excavation proceeds planks are inserted between the piles of the outside walls. They must be thick enough to transfer the earth pressures to the piles. The accompanying charts (Fig. 15) are used to determine the required thicknesses. The use of the charts is illustrated by the following examples:

1. $s = 2.15$ m; $b_c \geqq 9$ m; $t = 9.60$ m planks 8 cm (no pressure from buildings)
2. $s = 2.00$ m; $b_c = 6$ m; $t = 9.80$ m planks 8 cm
3. $s = 2.00$ m; $b_c = 6$ m; $t = 13.90$ m planks 10 cm.

The planks between the piles on installation should be prestressed by hardwood wedge strips so that the earth behind them will not yield and cause damage to other structures, especially pipes under pressure.

If standard I-beams are used for the piles, a standard wedge strip is adequate, since the flanges of these profiles are sloped. However, if wide-flange beams are used as piles the wedge strips must be levelled on the excavation side in order to ensure adequate pressure of the planks when the wedge strips are driven into place (Fig. 16 and 17). If the outer piles are pulled after backfilling a guard plate should be placed between the pile and the protective concrete layer so that the concrete protective layer will not be torn loose with the waterproofing. The top metre of the vertical protective layer of B 120 concrete is provided with a steel wire mesh. If the piles are not pulled this reinforcement of the wall protective layer is unnecessary. If very fine sand is present (quicksand) the gaps between the planks which do not close tightly should be covered with 1.5 × 3 cm strips.

4.2.2 Size of shores

The shore dimensions are based on the following horizontal pressure components:

Earth pressure: $e_b = \frac{1}{2} \cdot 0.45\ t/m^2;$

$$t = 4.45\ e_t\ m$$

Traffic pressures: $e_v = \frac{1}{2} \cdot 0.275\ t/m^2;$

$$v = \frac{1.10}{1.80} = 0.61\ m$$

Pressure from buildings: $e_c = 0.45\ \ddot{u}'_c t/m^2$

$$\ddot{u}'_c = \ddot{u}_c - t'_c;$$

$$t'_c = +1.61\ m$$

$$\ddot{u}'_c = \frac{2.22 \cdot P}{3(2b_c + 0.60)}\ m$$

$$= \frac{14.8}{b_c + 0.30}\ m$$

The accompanying dimensioning table (Fig. 8; cf. Bautechn. 1957, p.19), is used to determine the required shores. The use of the table is illustrated by the following examples:

(1) $t = 5.75$ m;
$b_c = 4.00$ m;
$e_v = \text{const.}$;
$l = 10.00$ m;
$t_c = 9.45$ m;
$h_s = 3.50$ m;
$\phi = 32$ cm;
$s = 2.00$ m;

(2) $t = 12.95$ m;
$b_c = 6.00$ m;
$e_v = \text{const.}$;
$l = 10.00$ m;
$t_c = 14.40$ m;
$h_s = 4.00$ m;
$\phi = 36$ cm;
$s = 2.00$ m.

4.2.3 Construction of shores (struts)

If a shore cannot be placed horizontally or at right angles, the shore end should be secured against slipping by providing steel sections or timber supports in both directions wherever the angle of slip is more than 5°. The standard outer pile interval in the horizontal direction is 2.0 m corresponding to the standard outer pile interval. The vertical distance between shores should not exceed about 3.25 m, for peripheral shoring 4.00 m and in exceptional cases down to 10.00 m depth, 4.50 m, using an allowable stress of $\sigma_e = 1800$ kg/cm². As far as possible, however, peripheral shoring should be avoided.

4.2.4 Vertical position of shores

The shore position should be chosen high enough above the construction joint in the wall below it so that the application of the waterproofing will not be hindered by the junction point of the steel reinforcement, i.e., where

d = 20 mm steel rods with 1.40 m interval

d = 26 mm steel rods with 1.65 m interval

are used.

On the other hand the second construction joint of the wall must be at least 42 d below the top of the roof slab.

Where the vertical position is restricted a distance from a point about 20 cm below the construction joint to the shore of about 1.10 m is required where the shore is above the [-section. This is necessary to allow a proper waterproofing joint. In the case of a shore directly on the [-section 0.80 m is sufficient (Fig. 18).

The vertical level of the shores should also be chosen so that they will not have to be changed on account of existing cables and pipes. If the road deck beams are also used for shoring, thereby eliminating the top shores, the buckling length of the I-sections should be reduced by longitudinal shores $\gtreqless \phi$ 20 cm at the centre when λ exceeds 200. For cantilever action of the piles above the top shoring position, with a steel stress of $\sigma = 1600$ kg/cm^2 a cantilever length of about 2.00 m is obtained. If these stresses were to be exceeded by more than 12.5% for a comparatively long time due to the construction work it would be necessary to install temporary shores at the top end.

4.2.5 Support of shores

On the central piles all shores should be supported in the [-sections which are bolted directly to the piles. The space between the two [-sections at the supporting position of the shores should be filled with a suitable piece of round timber which is specially secured against dropping.

On the outer piles the shores should be supported in a [-section which spans at least two bays and is bolted to the pile. The shores should be secured in position by two hardwood wedges driven simultaneously. So that the wedges will not be weakened by the provision of holes for the heads of bolts, hardwood liners of 15 mm thickness should be inserted between them. The purpose of the continuous [-section are: to ensure the correct spacing of the outer wall piles, to prevent rotation of the piles, to distribute the earth pressure more uniformly on to the shores, and, in certain cases, also to act as supports for the road deck beams. This is assuming the standard shore spacing according to 4.2.2 (Fig. 18 and 19). At the lowest shoring position in exceptional cases beam claws can be used (Fig. 20 and 21) instead of the continuous [-sections for supporting purposes when local considerations or rapid progress in construction make this desirable, provided opposite piles allow vertical shoring; otherwise it will be necessary to use [-sections here as well. If the piles, especially IP-sections, are strong enough to permit spans up to 4.50 m, particularly where there are [-sections exactly perpendicular to the axis of the tunnel, the [-steel beam can also be placed below the shoring position. For wedging up the shores hardwood wedges of at least 2.5 cm average thickness should be used.

4.3 Diagonal bracing (Fig. 22)

The arrangement and design of the bracings should be determined in the shoring plan (Fig. 19, 23, 25, 26). The first principle is that all measures for securing the tunnel excavation depend on the weakest point of the shoring construction. The type of construction is evident from the figures. Fig. 24 shows the excavation without transverse bracing.

4.3.1 Vertical lonitudinal bracing (Fig. 23)

The central piles are subjected to vertical forces from the dead load of the shoring system,and, when the excavation is covered by a deck, also from the dead load of the deck, as well as from traffic and possibly also from the equipment being used in construction. The central piles also have to take some horizontal forces in the longitudinal direction because the shoring system is not always straight-lined and because of deceleration and acceleration of vehicles on the deck. Dischinger[8] in his report on the serious cave-in during the building of the Berlin North-South S Route, pointed out that here, as in most construction accidents, the cause lay in a lack of stability. The dangers from having the piles too short had not been fully realized and while precautions had been taken to prevent vertical displacements, nothing had been done to prevent horizontal movement. In this connection it is again emphasized that in all excavation shoring operations the joints should be protected against displacement in all directions by diagonal bracing.

Diagonal braces should be installed between the central piles for protection against longitudinal displacement. The steel cross-bracing should be placed between the upper shore levels in every second central pile bay in the case of three to four shore levels, and over the entire length of the excavation in the case of five or more shore levels (Fig. 23).

To transfer the longitudinal forces from the diagonal bracings of the upper part of the centre wall to the ground, at certain intervals two central piles should be reinforced down to the floor of the excavation by structural steel cross-bracings. These should be installed: on straight stretches and at curves with a radius $\geq$ 500 m,

with single piling, in every eighth or sixth bay,
with double or more pile rows, in every fourth bay;

on curves of $<$ 500 m radius

with single piling, in every fourth bay,
with double or more central pile rows, in every third bay

on curves of $<$ 250 m radius,

with single centre piling, every third bay,
with double or more central pile rows, in every second bay.

At transitions from single to two or more central pile rows and where central piles are staggered, the end bays are to be provided with structural steel cross-bracing from top to bottom. In case of normal construction this cross-bracing can be omitted in the bottom part. In general one full bracing in the second bay is sufficient up to three staggered bays.

4.3.2 Horizontal and vertical bracing (Fig. 19, 25, 26)

In excavations without central piles, bracing is not generally necessary. On curves of less than 250 m radius the use of bracing should be decided upon from case to case. In order to use the outer walls for absorbing the horizontal longitudinal forces occurring in the central piles, one horizontal bracing should be installed at one shoring level next to a vertically reinforced central pile bay, in deeper excavations this should be done at two shoring levels. The bracing should be independent of the shores. These bracings should be placed wherever possible above the tunnel ceiling so that they interfere as little as possible with the work on the tunnel and can remain in place until the tunnel is finished. In excavations with single central piles the bracings will be in the form of a cross-brace (Fig. 25). In the case of two rows of central piles the bracing must be designed as a double-braced construction (Fig. 26). The horizontal bracing should be installed every eighth central pile bay and should be made of structural steel.

A vertical bracing should be installed between the first and second shore levels in combination with the horizontal transverse bracing in every eighth central pile bay (Fig. 19).

The horizontal and vertical bracing should be made of structural steel. Under difficult local conditions the arrangement of the transverse bracing should be determined individually.

4.4 Connections and joints

For the connections and joints of structural steel sections, 4D bolts and standard holes should be used. The bolt threads should not extend into the holes. The holes should not be flame-cut but must be drilled, for 20 mm bolts with a diameter of 21 mm and for 24 mm bolts with a diameter of 25 mm. The joints in the channel walls must not be made at the piles but must be placed in the spaces between the piles and the road deck supports. The connections should be calculated for tension (each with two 20 mm bolts) and for additional bending. Any earth pressure in the y-direction should be taken into account separately. If at the same time they carry the road deck see Sec. 3.8.5.

Welded joints may also be used if made by approved welders.

In order to keep down the number of types of bolts at the building site, only 20 mm (4D) and 24 mm (4D) bolts should be specified for the bolted joints, which should be calculated from case to case.

4.5 Road deck (Fig. 27)

4.5.1 Road deck beams

The road deck beams should be laid directly on the uppermost channel sections of the outer walls, always near the piles, and bolted down tightly. The allowable distance from the pile must be calculated. If possible wide flange beams should be used when the road deck carries streetcars (Fig. 28 to 32, showing details at points 1-8). In excavations with one or more central pile rows the road deck beams should generally be placed in staggered arrangement on the cross-beams of the central rows and should be supported on the channel sections of the outer walls adjacent to the piles, so that each beam represents a girder on two supports (Fig. 28). Where the deck beams extend across two bays they can be made continuous, as girders on three supports.

The uppermost channel sections and the cross-beams of the central rows also accommodate the head shores, which are used only for a half-open excavation (Fig. 29) and in the region of the bracings (Fig. 23). If the road deck beams are also used as shores for the excavation and if the load on the cantilevering end of the pile is 1800 kg/m^2 (point 1 and 2 in Fig. 28, point 5 in Fig. 30) they should be fitted with knee-braces or horizontal channel sections.

4.5.2 Bracing against deceleration forces

For transmitting the deceleration forces due to braking of vehicles to the outer walls, except in the case of narrow excavations up to 6 m in width where the continuous road deck beams transmit them directly, special brake force bracings should be provided at intervals of not more than 30 m in the region of the horizontal bracings. Their position will depend on the local conditions. For example, brake force bracing should be provided near rail switches and near bus stops, since this is where braking occurs most frequently and regularly. These bracings are made of angle steel sections bolted to the bottom flanges of three road deck beams as diagonals so that these road deck beams and angle sections together form a horizontal lattice bracing (points 1 to 4 in Fig. 28 and 29). Adjacent beams should be forced to contribute by providing a longitudinal stiffening of not less than 20 cm diameter timbers laid parallel to the tunnel axis at half the height of the I-beams whenever the beams by themselves no longer suffice for the transmission of the braking forces to the outer walls. The bolted joints between the road deck beams and the cross-beams serve primarily to absorb the brake forces. In the zone of the brake force bracing the three beams should also be stiffened near the supports with round timbers of 20 cm diameter. In any case the brake forces should be transmitted to the fixed points which are formed from the horizontal and vertical bracings, the braking forces being considered as an additional load. If possible, therefore, one of the brake force bracings should be placed directly above the fixed point; if this should lead to too complicated connections then the braking force should be carried directly downwards by diagonals.

4.5.3 Expansion joints

If continuously welded embedded rails have to be exposed the traffic authorities should be urged to provide expansion joints in order to prevent the rails from buckling.

4.5.4 Decking of roadways

According to the Street Traffic Regulation the road decking for standard loads consists of 12 × 18 cm timbers which shall be butted only over the beams, and 5 cm thick wooden planks laid over them. In exceptional cases only, e.g. at double street intersections, hardwood planks should be used. As soon as the planks are worn down 2 cm by the traffic they should be replaced. At transition points from road decking to pavement protective angle pieces

50 × 50 × 5 should be installed which enclose the plank surfaces (see details of Fig. 28 - 32).

The squared timbers should be laid longitudinally with no gaps between them. They should be kept from moving by angle steels every 30 m. The lateral space between timbers should be 1 cm. These gaps should be maintained by liners.

4.5.5 Decking of sidewalks

If the excavation extends under the sidewalks the squared timbers should be arranged as shown in Fig. 32, even though this is not required for the normal sidewalk load, since this will take care of the possibility of vehicles running up over the curb. Wooden planks 5 cm thick suffice for decking. The sidewalk edges should be provided with 50 × 50 × 5 angles.

4.5.6 Decking of streetcar tracks

If ordinary rails are used the streetcar tracks should be laid on sleepers as shown in Fig. 28 and 29. The sleepers are carried on longitudinal girders which are wedged firmly between road deck beams and rest on the bottom flanges. If I-beams are used as road deck beams, adequate supporting surfaces for the longitudinal beams should be provided, if necessary by welding 125 × 300 × 10 mm bearing plates or capped I-section flanges. The sleepers should be secured on the longitudinal beams and the latter in turn should be fastened to the road deck beams by brackets, round-timber props and angles to prevent their displacement in any direction. To prevent displacement of rails special shackles or protecting clamps should be installed at intervals of not more than 30 m, the connections of which should be calculated. All wedges, liners and shims should be fastened down.

5. Concluding Remarks

The instructions which have come into use since 1953 have proved effective especially with regard to the required safety in the excavation work on the Seestrasse-Kurt-Schumacher-Platz section of subway line C, so that no critical circumstances have arisen during the construction. The execution of the method was satisfactory as shown by the acceptance of that section of the subway.

On the 3rd of May 1956, this 2.4 km section with the three stations of Rehberge, Afrikanische Strasse, Kurt-Schumacher-Platz (Fig. 33) was opened to traffic after a building period of 2 1/2 years.

The following figures give some idea of the scope of the operations: 26,000 m of piles were driven, 14,000 m^2 of road decking was laid, 40,000 m^2 of planking and 35,500 m of shores were installed: 230,000 m^3 of ground were excavated, 108,000 m^2 protective coating with 82,700 m^2 of 3-, 4- and 5-ply waterproofing were applied and 65,200 m^3 of concrete were placed with 3400 tons of reinforcement steel. The aggregate consisted of 40% of West Berlin gravel sand, and 60% of crushed brick, added in grain sizes 3 - 7, 7 - 15 and 15 - 30 mm. The quality of the concrete was B 225.

In lowering the ground water the 136 underwater pumps lifted about 15 million m^3 of water.

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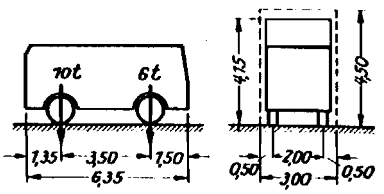

Fig. 1

Heavy truck; standard load
for 16 ton truck

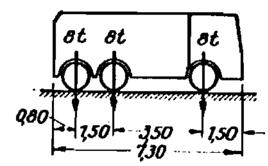

Fig. 2

Heavy truck; standard load
for 24 ton truck

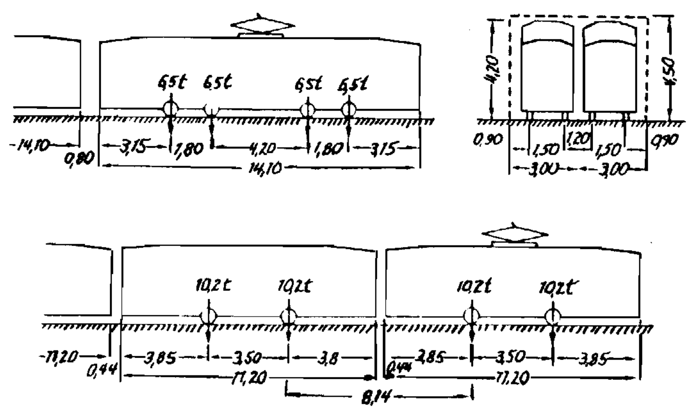

Fig. 3

Streetcar; standard loads for
types TED 52 and TM 3

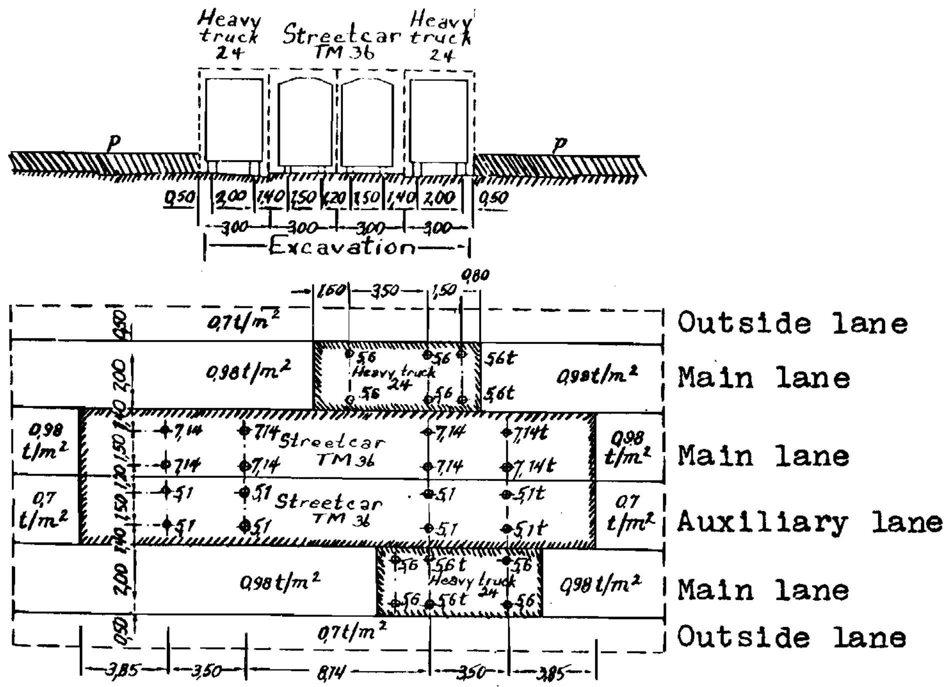

Fig. 4

Road deck beams. Load including streetcar

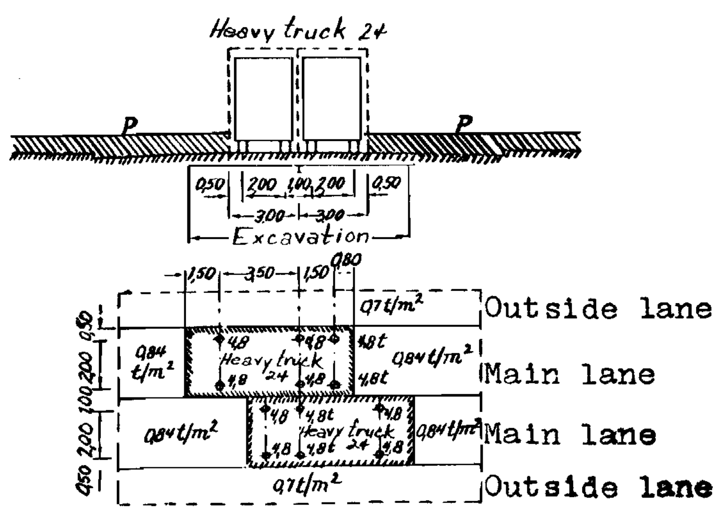

Fig. 5

Road deck beams. Load not including streetcar

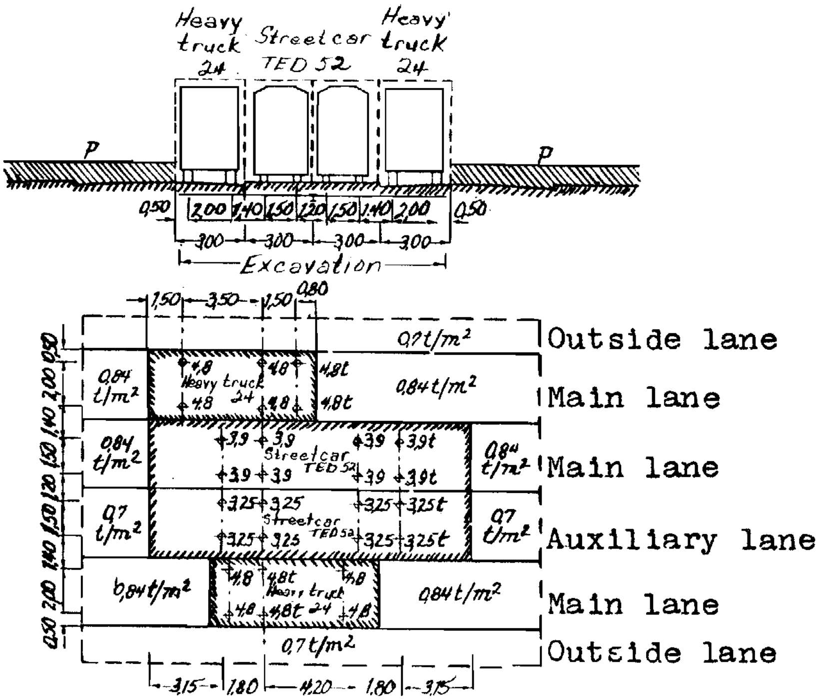

Fig. 6

Road deck longitudinal beams. Load including streetcar

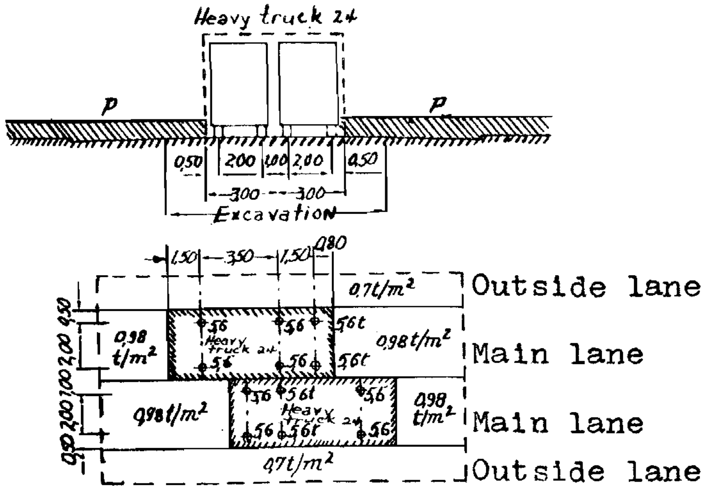

Fig. 7

Road deck longitudinal beams. Load not including streetcar

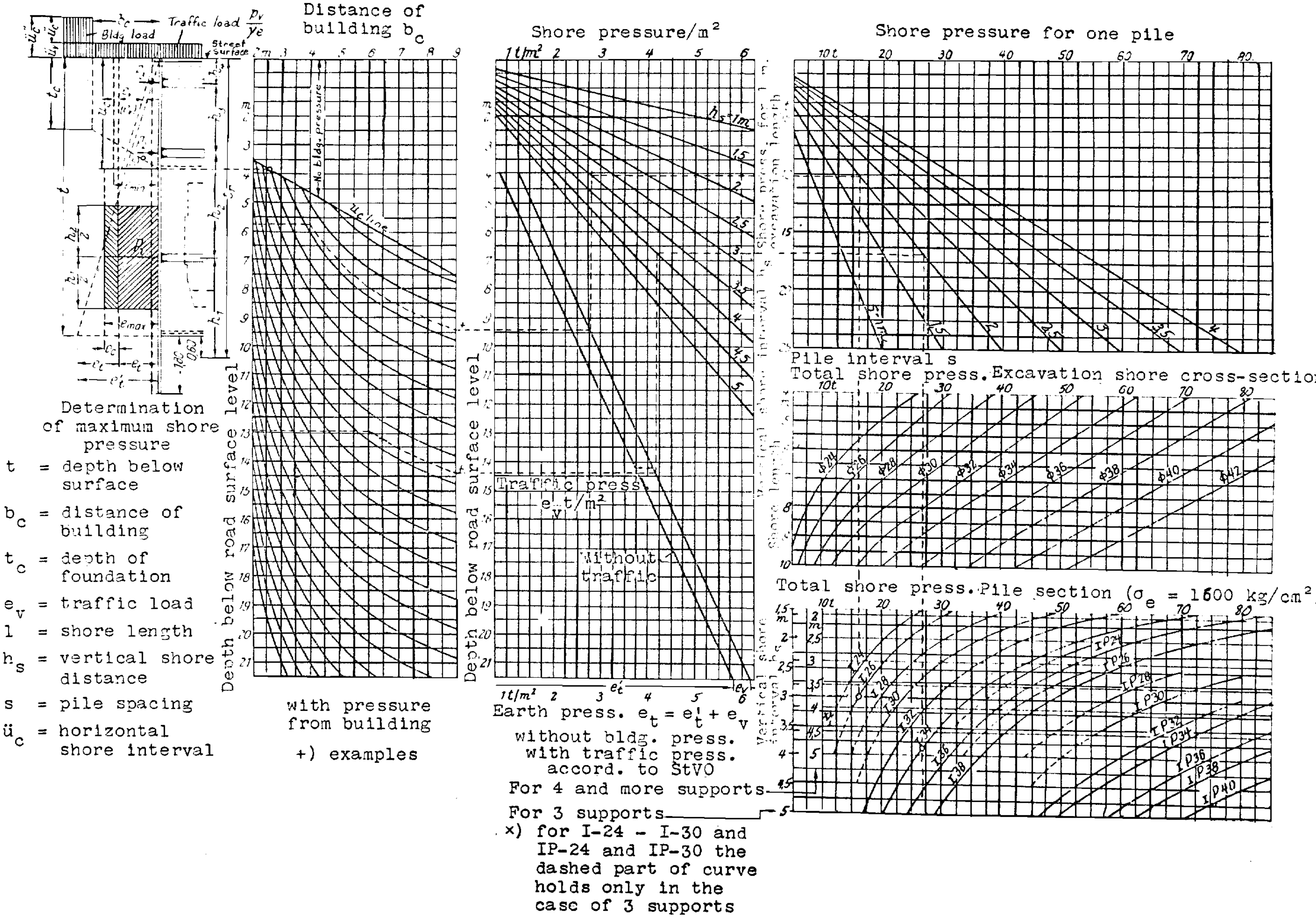

Fig. 8

Design diagrams for determining shore and pile sections

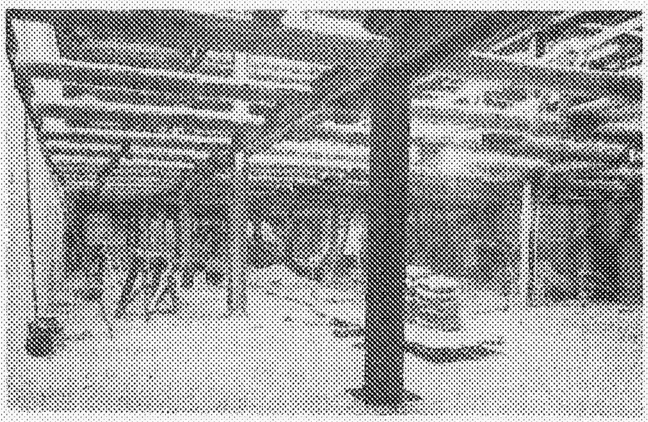

Fig. 9

Arrangement of central piles - Photo by Landesbildstelle, Berlin

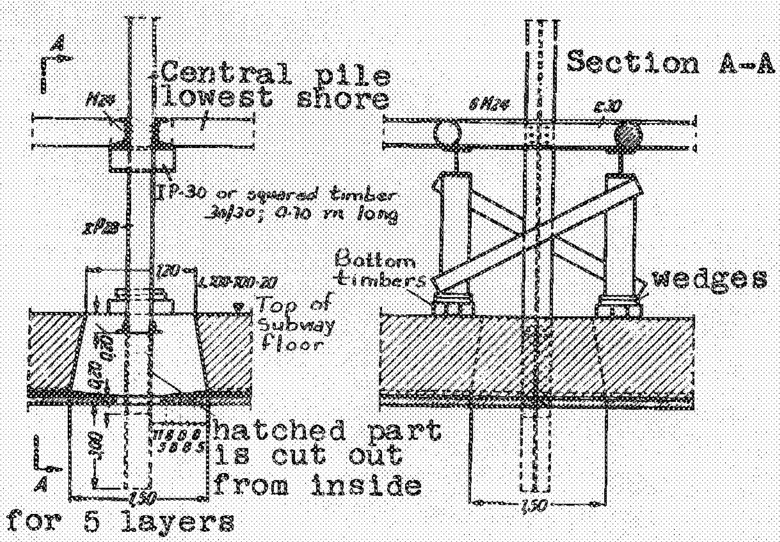

Fig. 10

Underpinning of a central pile on the subway floor

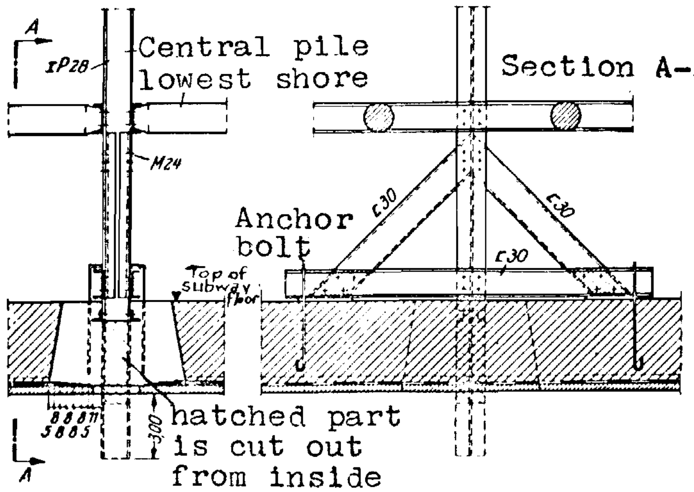

Fig. 11

Underpinning of a central pile on the floor in the vicinity of supplementary cross-bracing

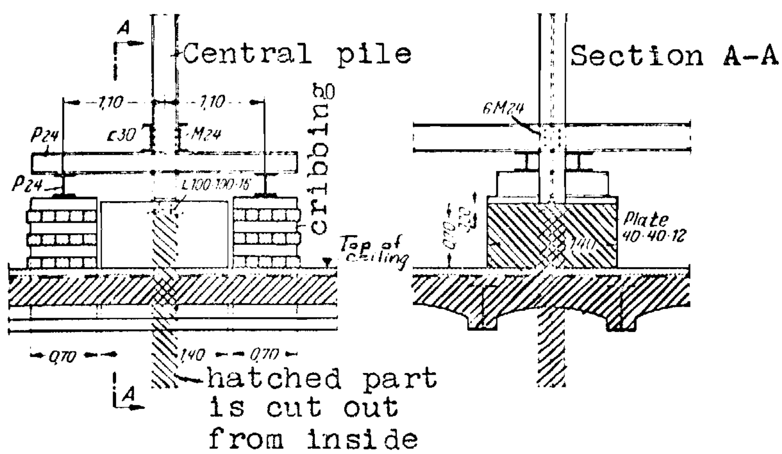

Fig. 12

Underpinning of a central pile on the ceiling

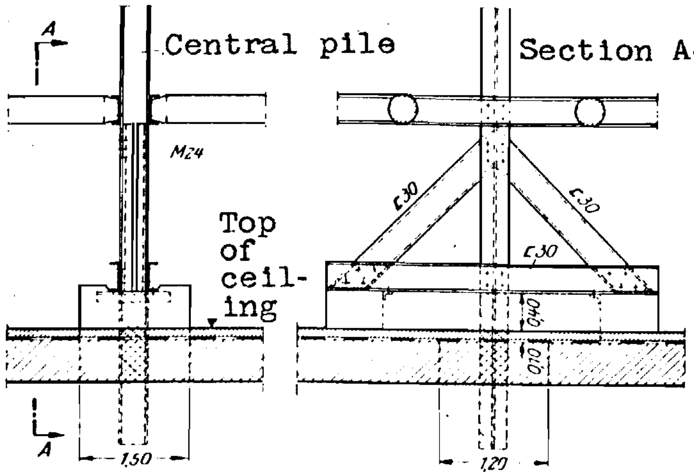

Fig. 13

Underpinning of a central pile on the ceiling in the vicinity of supplementary cross-bracing

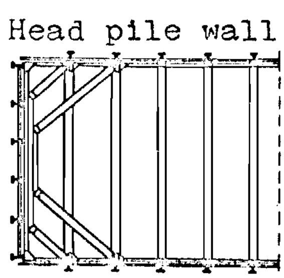

Fig. 14

Head pile wall of an excavation

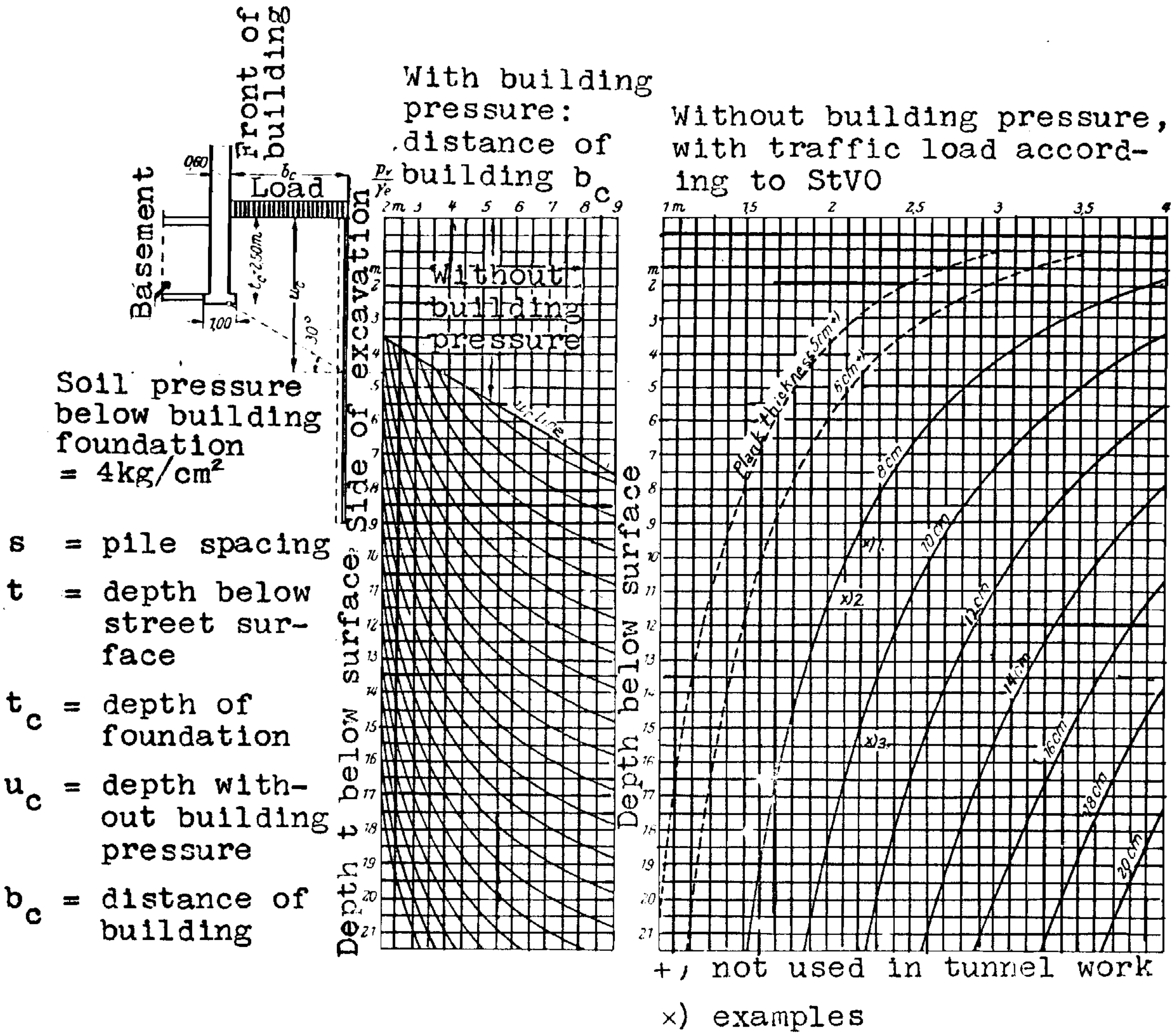

Fig. 15

Design chart for determining plank thicknesses for lagging

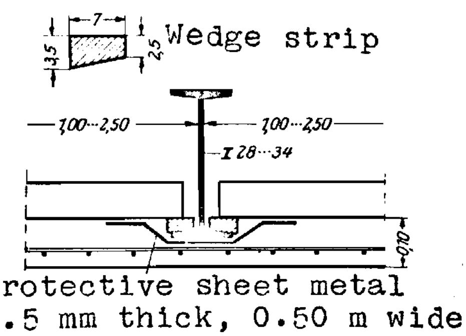

Fig. 16

Wedging of lagging at I-piles

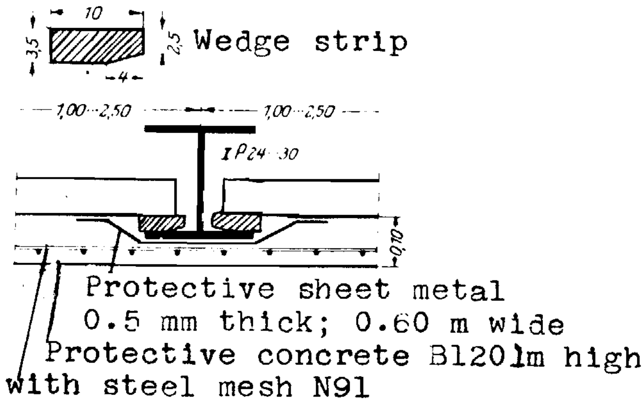

Fig. 17

Wedging of lagging at IP-piles

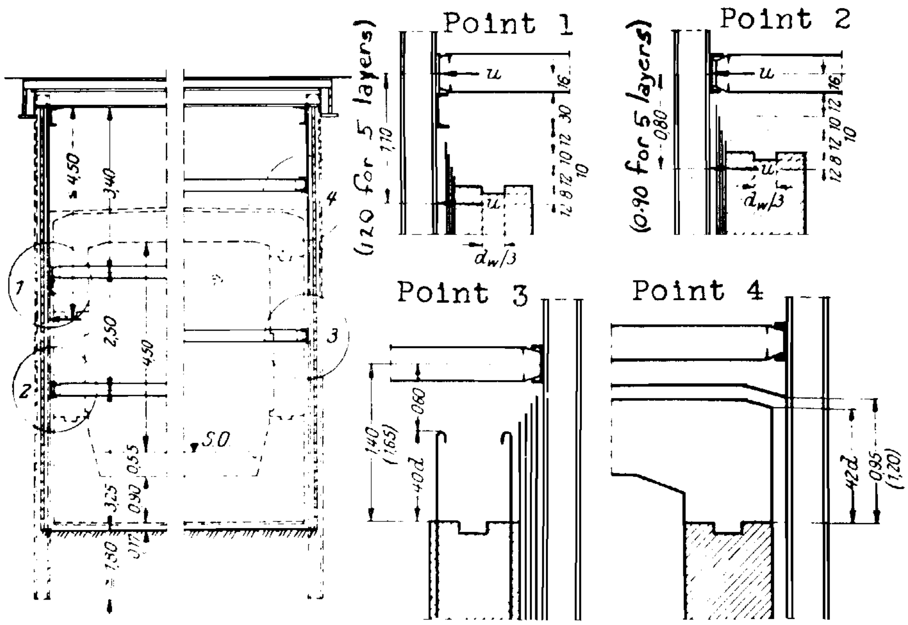

Fig. 18

Vertical positions of shores

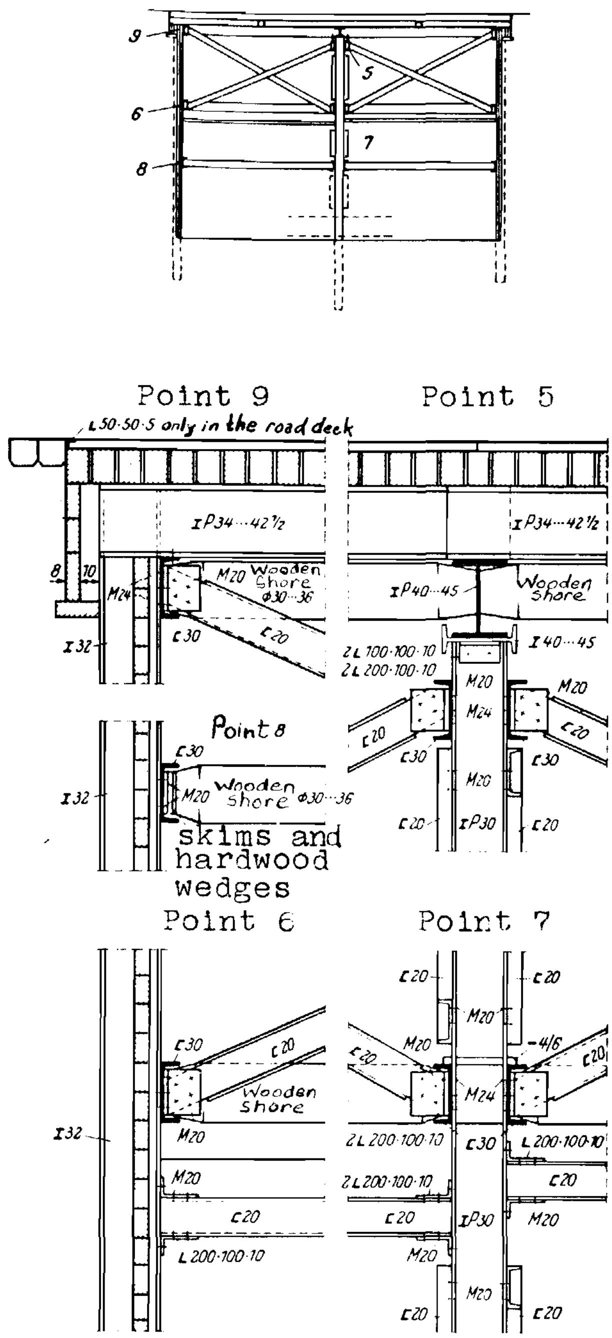

Fig. 19

Vertical bracing for excavation strengthening

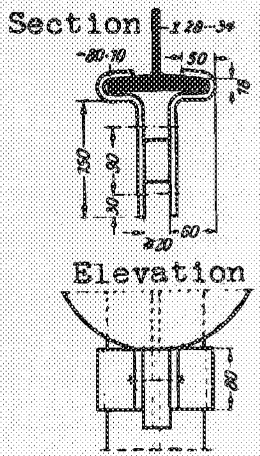

Fig. 20

Beam claws on I-sections

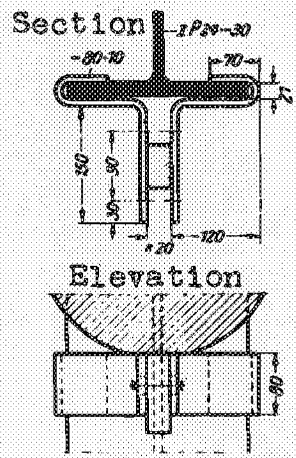

Fig. 21

Beam claws on IP-sections

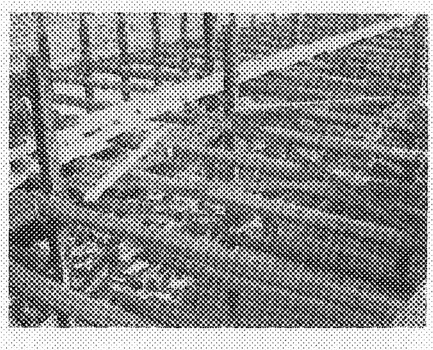

Fig. 22

Shoring of excavation and arrangement of
bracings - Photo by Landesbildstelle, Berlin

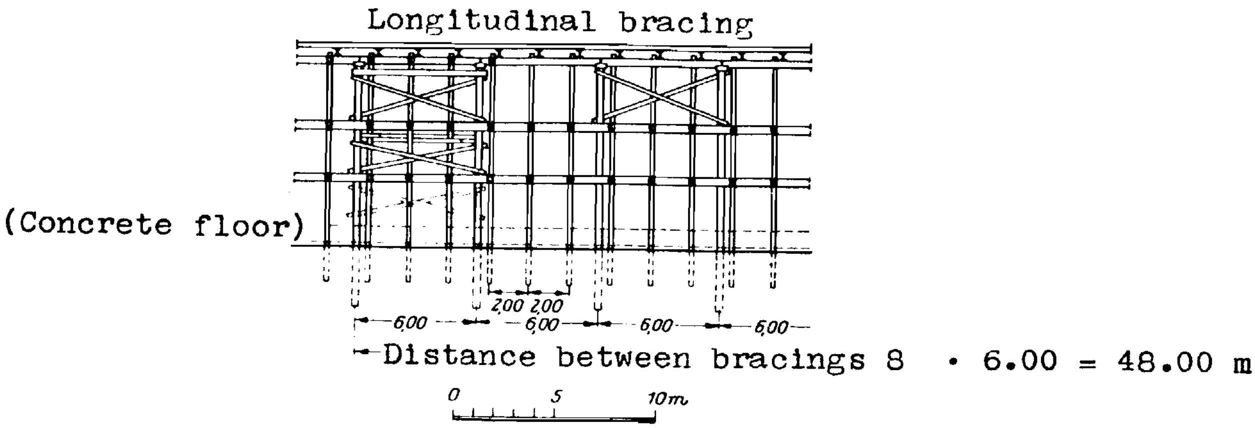

Fig. 23

Longitudinal bracing for excavation shoring

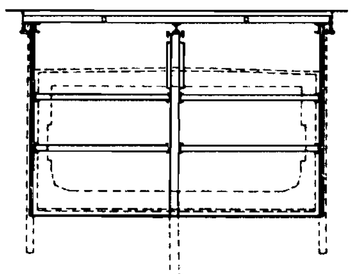

Fig. 24

Excavation without lateral bracing

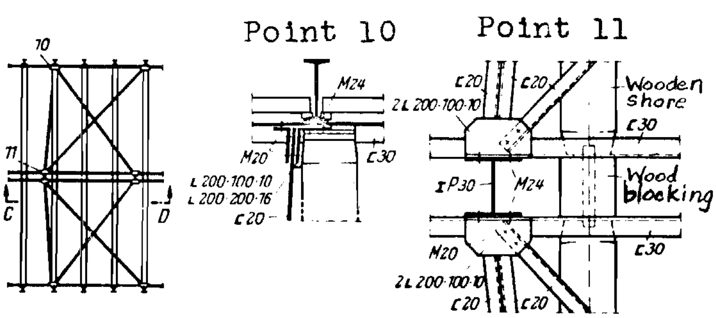

Fig. 25

Horizontal bracing for excavation shoring
in the case of one central pile row

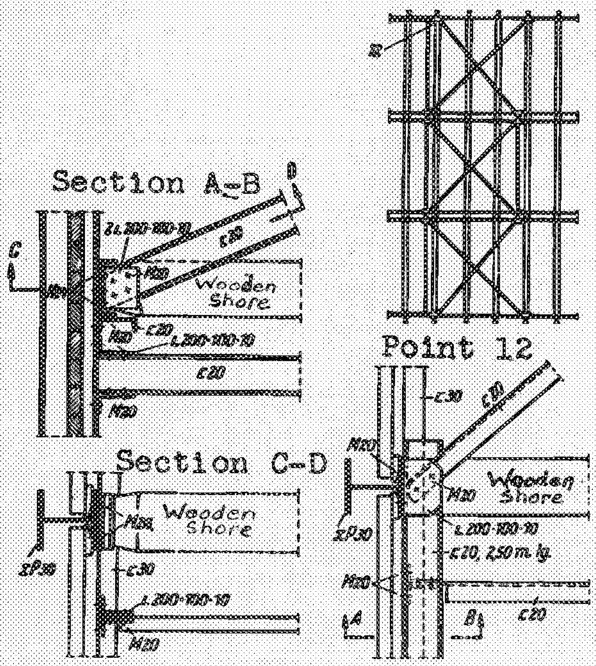

Fig. 26

Horizontal bracing for excavation shoring in the case of two central pile rows

Fig. 27

Decking of roadway below streetcar rails - Photo by Landesbildstelle, Berlin

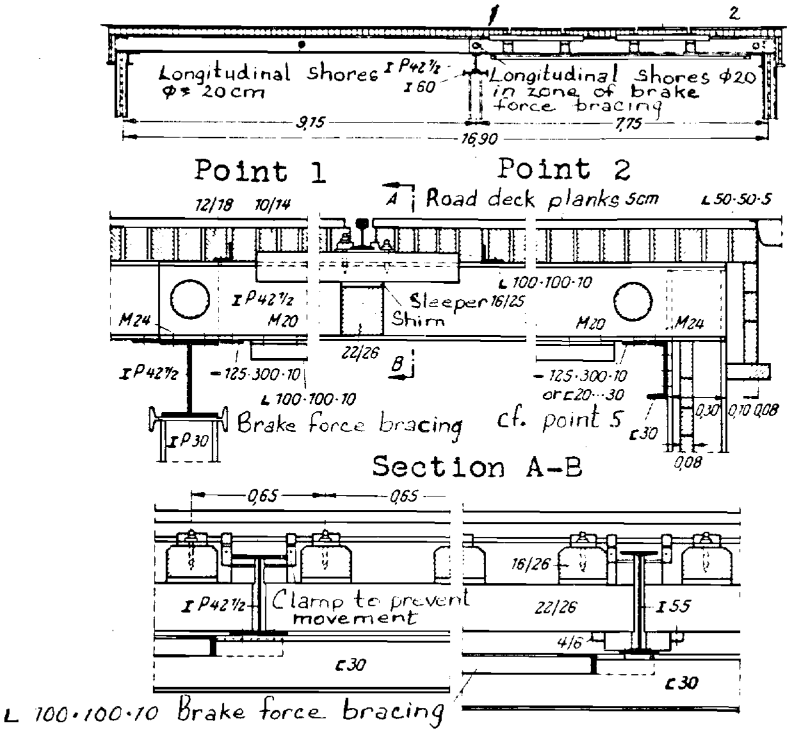

Fig. 28

Decking over the entire excavation
with support of streetcar line
with ordinary rails

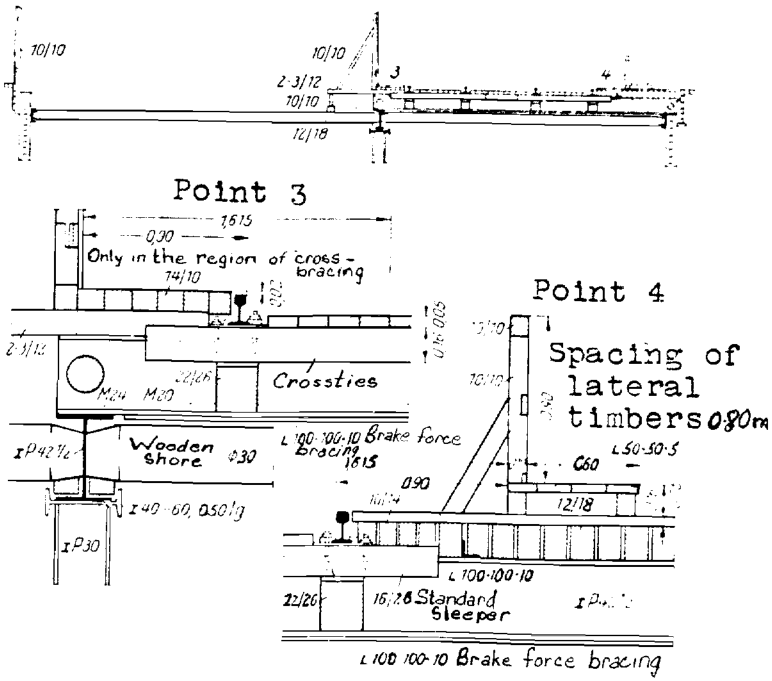

Fig. 29

Excavation decking for a half open
excavation and support of
streetcar line with
ordinary rails

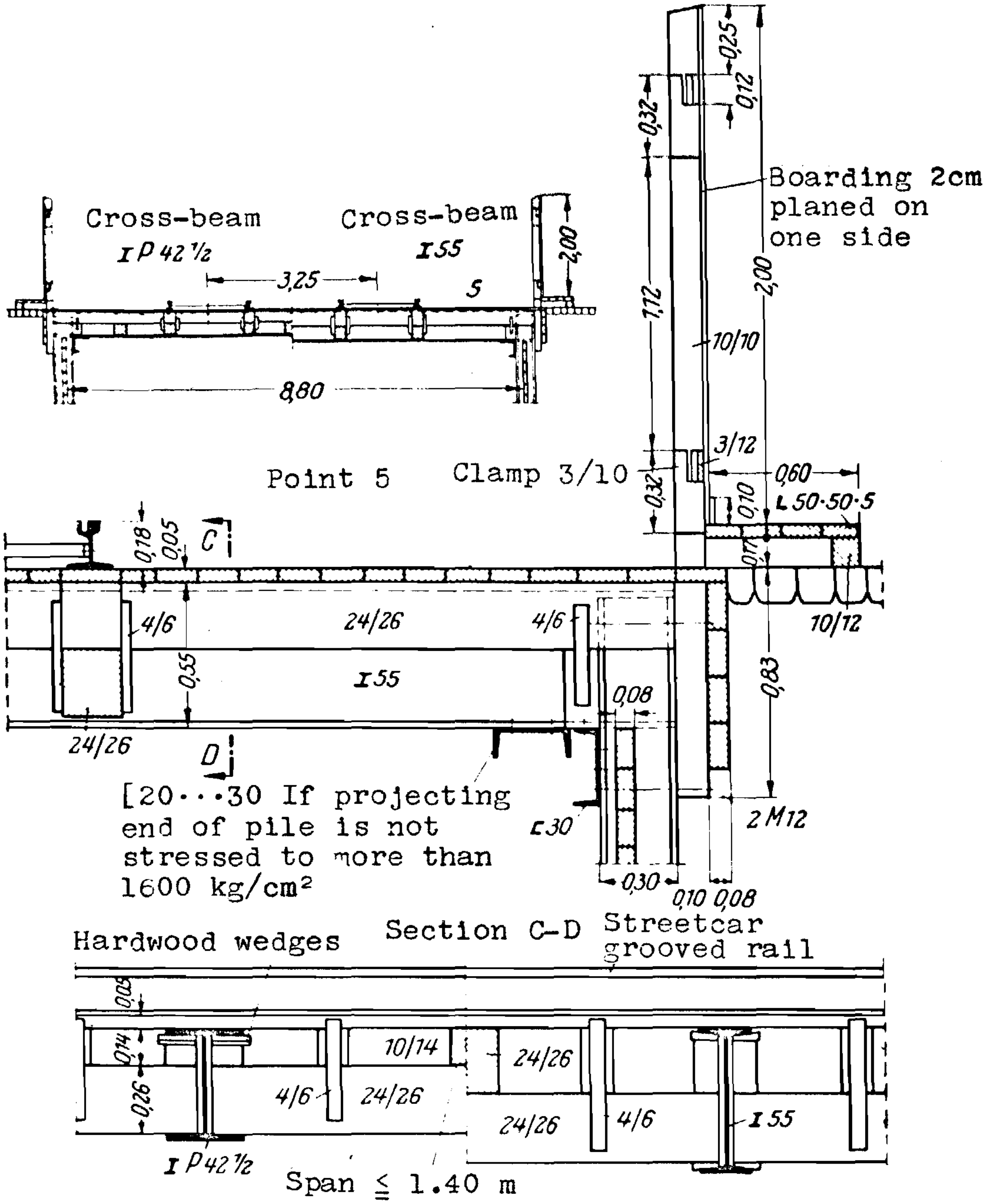

Fig. 30

Support of streetcar on grooved rails

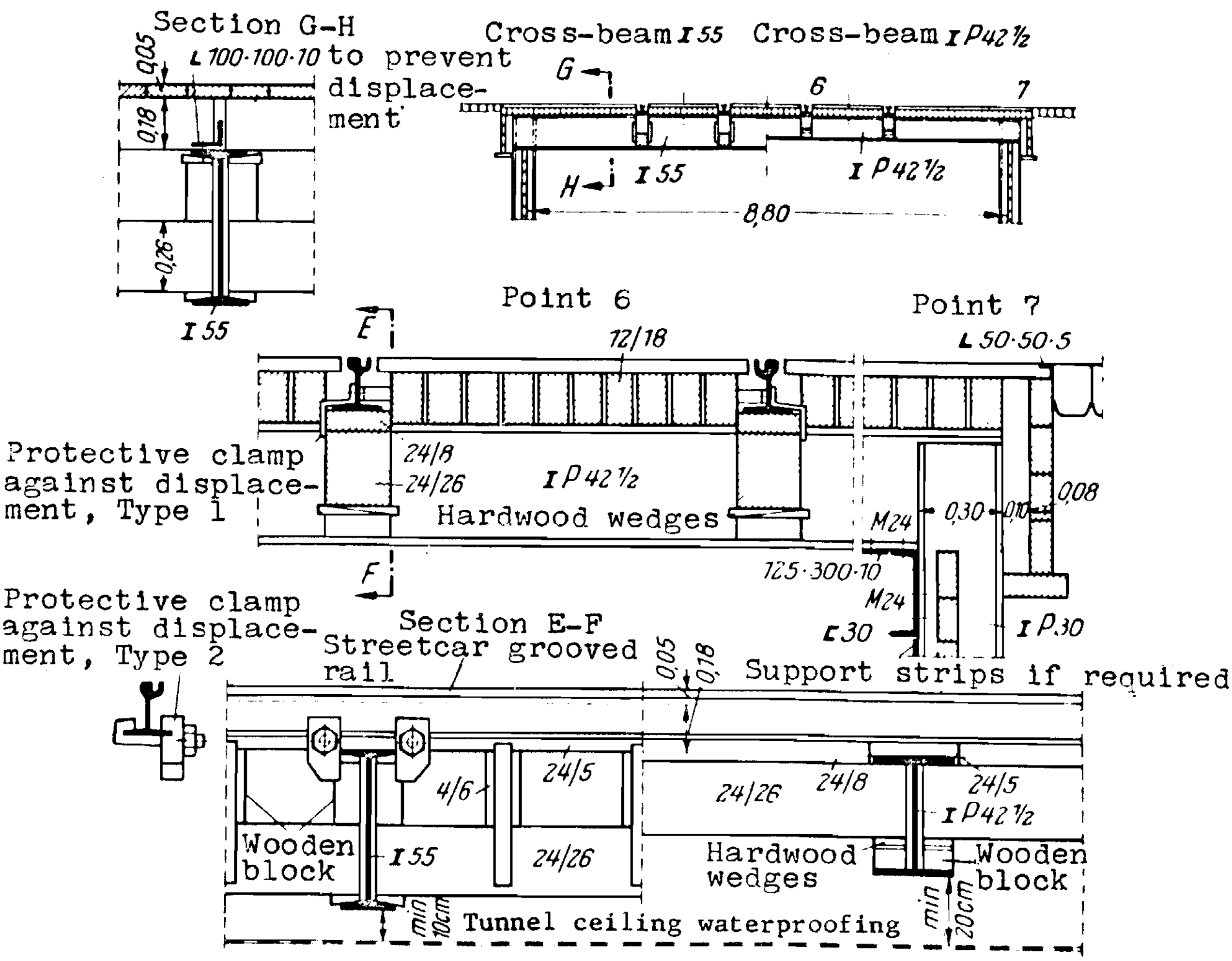

Fig. 31

Excavation decking with support of streetcar on grooved rails

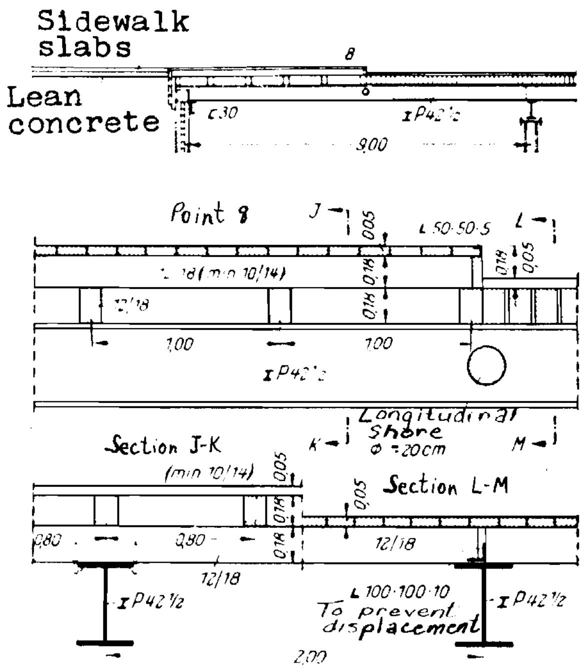

Fig. 32

Sidewalk decking

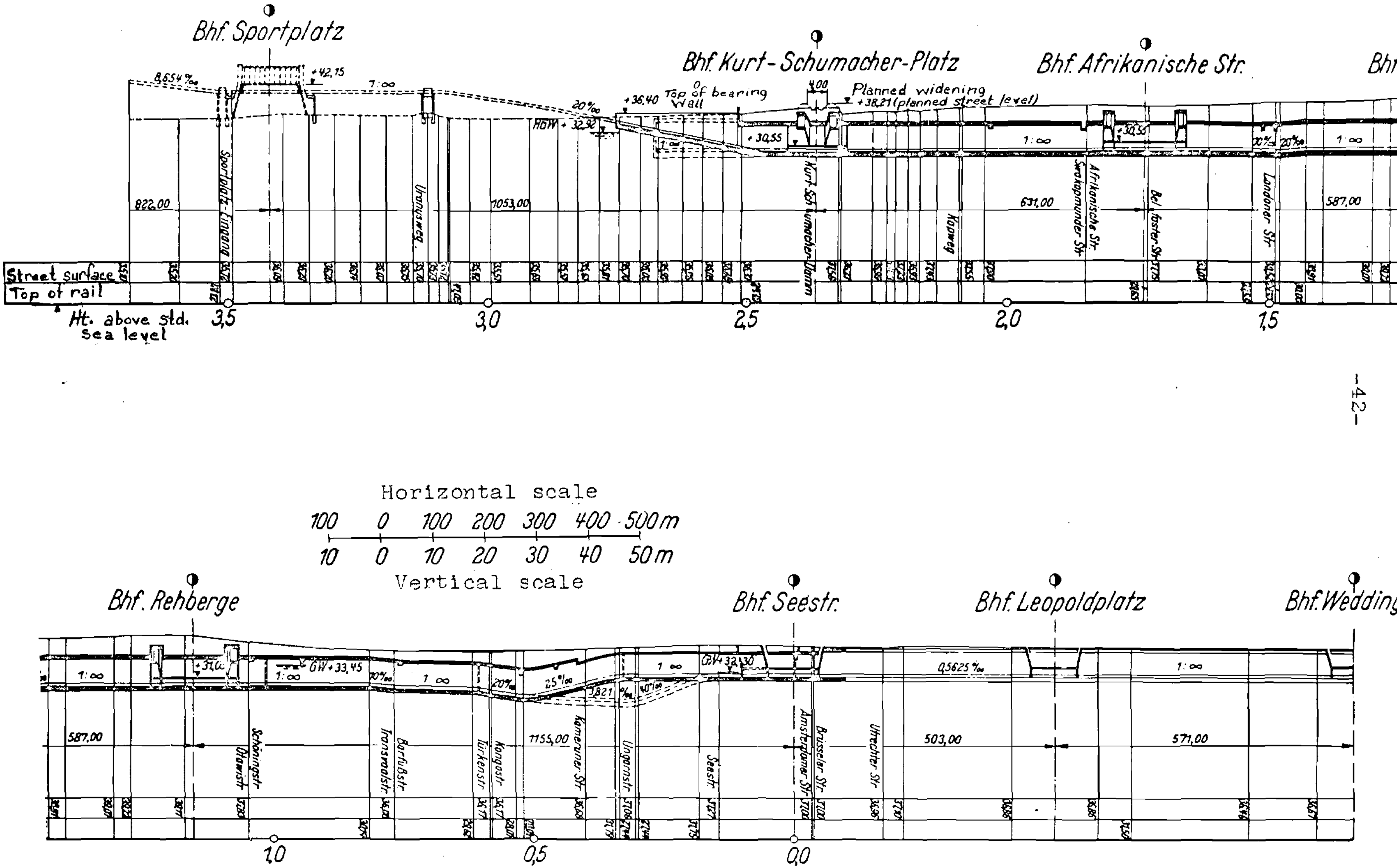

Fig. 33

Longitudinal section