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Use of Concrete in Dam Construction in Germany.

Beton im deutschen Talsperrenbau.

L'emploi du béton en Allemagne dans la construction des grands barrages.

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1. Concrete dams and retaining walls.

The Dreiläger barrage in the slate hills on the left bank of the Rhine was the first barrage in Germany to be constructed of concrete. It was erected as early as 1909 to 1911. Nevertheless, it can hardly be considered as the precursor of modern concrete barrages because it was made of concrete solely for the reason that no appropriate building stone could be quarried near enough for purchase at an economic figure. In addition, neither in design nor in construction does it possess a single feature of modern concrete structures: highly developed mechanisation, suitable size of broken stone aggregate, high water-cement ratio, density and form of cross section developed in keeping with the special characteristics of the building material. In fact, the wall was constructed of tamped concrete and designed in accordance with principles very commonly used in Germany and originally introduced by Professor *Intze* when devising his Rhenish-Westphalian rubble-stone style of dam construction. The Dreiläger dam is a curved in plan, the water face has a compact rendering with a 0.7 m thick protective rubble stone covering and earth-work at the base, while the upper part of the wall (10 m) consists entirely of rubble stone masonry.

In spite of a few cracks, slight perviousness of the original work joints and signs of suiter formation on the outer face, the dam is in fairly good condition, but, for the reasons outlined above, it has had little influence on the development of German barrage construction.

The Schwarzenbach Dam (Fig. 1), in the northern part of the Black Forest, was started in 1922 and marked the beginning of the construction of modern concrete barrages in Germany. Although there are some excellent granite quarries quite near the site, so that, according to views held until recently, a quarry wall would have seemed the most natural solution, those responsible for the building decided after careful consideration that the dam, which was to be a huge construction for those times, should be of cast concrete. This decision was reached mainly in order to reduce the time required for construction and to meet the difficulty, not to say impossibility, of obtaining at that time — shortly after the Great War — the requisite skilled labour (400 men) and of keeping them for the long building period in a somewhat remote district. Then, too, there was the uncertainty as to the possibility of constructing a really satisfactory watertight quarry wall and, lastly, the necessity for reducing cost.

It is perhaps comprehensible that at that time there was a tendency to maintain the methods introduced by *Intze*, which had proved their value in connection with rubble masonry in Germany, and this led the Board not to take full advantage of the possibilities of this new building material. Consequently, the waterside of the Schwarzenbach Dam was not only made impervious with a gunite rendering and a protection paint coat, but in addition, a further protection lining 0.8 m thick to resist atmospheric and mechanical agents, was applied which again was surfaced with gunite in dovetailed connection with the core wall. These far-reaching and

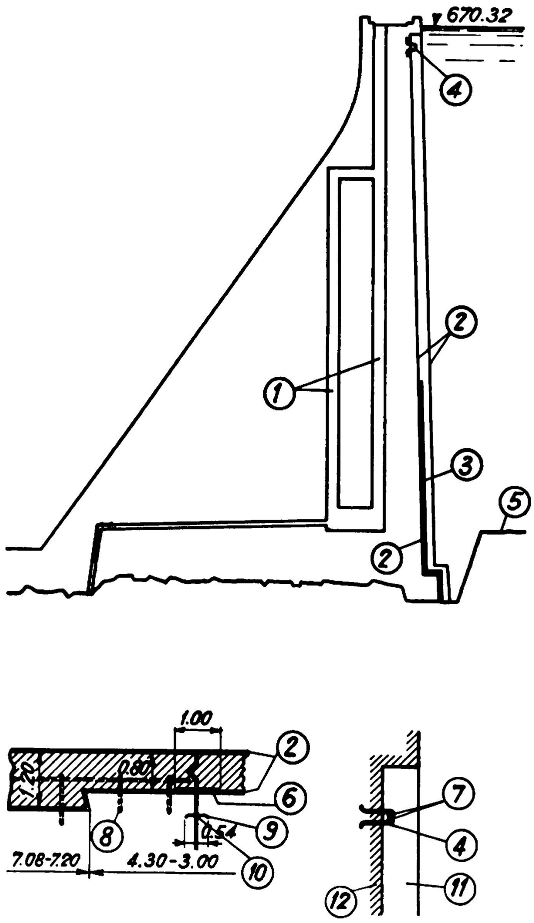

Fig. 1.

Schwarzenbach Barrage.

1) Inspection shaft.
2) Gunite 2.5 cm.
3) Tarred paper insulation.
4) Anchor (stirrups).
5) Rock surface.
6) Three-ply of tarred paper.
7) 2 longitudinal bars 20 mm.
8) Stirrup (at crown).
9) Copper sheet.
10) Tarred rope.
11) Shell.
12) Heart of wall.

really effective methods, which had been introduced by *Intze* and subsequently adopted for the majority of German rubble stone retaining walls with only slight improvements, were applied in still further measure in the lowest third of the Schwarzenbach Dam. Instead of the protective paint coat on the inner surface of the torcrete, a particularly strong insulating layer of three-ply asphaltic cardboard was applied hot. The fact is that the streams of the Black Forest are very soft and sometimes contain free carbonic acid and marsh-acid which give them properties as injurious to cement as those of certain streams in some of the primordinal rock regions of Scandinavia, and it was therefore decided to eliminate this drawback as far as possible in this first attempt of applying concrete to work of this kind. Of course, laying the protective covering and the need for double sluttering for the water face, in addition to the complications of making a really thin protective facing, added to difficulties and to cost.[1]

The facing of the downstream side of the wall also of an expensive character; it consists of a layer 1 m thick of coursed granite masonry, the main object was that of appearance.

Although this wall had been constructed in a hilly district having a high rainfall and much snow (670 m above sea level) it has given the last ten years after being put in commission no repairs worth mentioning. There are no signs of damage on either the upstream or the downstream face. On the water face below the coping wall small deposits of lime, probably due to leakage after heavy showers, affected the outside gunite rendering slightly so that this had to be touched up.

When the reservoir is full there is a total leakage of 1 l/sec from the base and the vertical parts, while for the catchment pipe installed horizontally in the wall near the water face, the figure is 0.4 l/sec. In view of the height and size of the dam this result is very satisfactory.

The *Agger Valley* dam, the first and at present the only cast concrete barrage wall in the Rhineland, the home of *Intze's* rubble walls, represents a great improvement on the Schwarzenbach dam, built only a few years previously. The watertight layer on the water face in this dam was the first example in Germany of the use of facing concrete and there is *no* drainage system at the back. The outer face is lined with "Graywacke"-rubble masonry similar to the Schwarzenbach Dam.

The wall was cast by pouring the concrete through channels from two towers each 76 m high and it has lined expansion joints at equal distances of 30 m. One to two transverse (hair) cracks are visible in each concrete divisional block, particularly those at the ends of the barrage. The facing concrete on the water face has been slightly injured by frost. In the lower inspection passages there are signs of trickling. Signs of moisture are visible on the upper parts of the outer face which disappear in summer and which are probably caused by heavy rains penetrating from the crown of the wall and finding a way down behind the stone facing which was added later to the lined concrete. The maximum drainage of base of the wall (only for a full reservoir) is 1.0 l/sec. Only small quantities of water pass through the expansion joints after having shown originally a few leaks. The total maximum is 3 l/sec for the whole barrage. So far no repairs have had to be carried out.

The comparatively low *Zschopau* Valley dam, at *Kriebstein* in Saxony is the only Saxon retaining wall made by pouring the concrete from towers, although there are many concrete dams in Saxony, built at about the same time. The owners (Saxon Water Supply) considered the matter thoroughly before deciding to build it of cast concrete (as in the case of Schwarzenbach barrage).

The concrete mixture consisted of the following ingredients: 1 of cement: 0.38 trass concrete: 3.89 unusually rich aggregate. This corresponds, exclusive of the trass concrete to 320 kg cement per m^3 of concrete ready for use.

The watertightness of the water face is further increased by a facing of gunite 25 mm thick, rendered smooth and a three coats of inertol, and by drainage arrangement immediately behind this facing. The downstream surface is left unfaced, a new method in German barrage construction.

[1] Cp. Bautechnik 4. VI. 1926.

Apart from surface peeling the wall is in good condition and no repairs have been necessary.

The average annual seepage of the wall, which was very small right from the start, has been diminishing steadily ever since; in 1930 it was 0.14 and in 1935 0.026 l/sec self-caulking effect (Auto-densifying!).

The *Schluchsee* and *Schwarza* dams in the southern part of the Black Forest were built by the same Board (Baden Works), the same contractors (Siemens Construction Company) and partly by the same engineers as the Schwarzenbach dam, and the very different style of construction is a striking example of how opinion had changed in the course of a few years. These latter barrages are not made of liquid, but of "plastic" concrete, which instead of being brought to the site by channels was conveyed by belting and buckets and three rotary tower cranes.

The water face and the downstream surface are treated with facing concrete (0.75 and 1.00 m respectively) and given a further facing 1.50 m thick, in addition the water face has a rendering of torcrete 25 mm thick and a double coat of intertol. At the back there is a drainage system. The expansion joints are spaced at intervals of 12 to 15.5 m in the Schluchsee dam and 10 to 20 m at Schwarza.

In neither case has serious damage been observed on either outer or water faces; surface damage caused by frost and removal of shuttering, however, have warred the appearance of considerable portions of both faces. Most of the expansion joints which extended only to the foot of the service passage became subsequently elongated to the foot of the wall, this increase in length being due to crack formation.

The *Saale Valley* dam near the *Kleine Bleiloch*, built about the same time as the Schluchsee and Schwarza dams, is at present the highest barrage in Germany (70 m.) Unlike these two latter, it is built of cast concrete powred from a stationary concreting bridge, by means of vertical articulated pipes with dumping shovels worked by gravity mixers, to the lower part of which an arrangement of channels on rollers for pouring out the concrete is fixed. Neither the water face nor the downstream surface was treatet with facing concrete or plastering, but the wall was built of a compact mixture of Portland cement, Thurament[2] and crushed aggregate with a liberal admixture of water — about 240 litres per cubic metre of concrete.

The amount of heat developed in the wall, the changes in volume and movement of the blocks were kept under close observation. A number of large cracks formed, and here it is interesting to note that while the spaces between the expansion joints were fairly large — 25 m — four out of eight blocks cracked in the middle and radially even prior to the first filling of the reservoir. They were rendered watertight by dovetail chases cut into the water face, clinker masonry work being added, behind which a mixture of asbestos and bitumen was poured. The result was very good. In spite of this, however, the wall is not perfectly watertight; when the reservoir is full the drainage system on the water face carries a leakage of 25 l/sec. In one of the blocks the middle crack, which was filled up to make it more compact, has cracked further in an upward direction, so that water passes through this crack and flows straight into the drain pipe (16 l/sec when the reservoir is full). It is intended

[2] Thurament is a mortar ingredient composed of ground basic blast furnace slag; its binding power only develops when lime or cement is added. It is produced in Thuringia not far from the building site.

to improve this anti-leakage packing with a view to diminishing the amount of drainage water.

No other damages have been noticed on the outer surfaces of the Bleiloch dam since it was completed in 1932.

The *Zillierbach* dam in the Harz Mountains was not completed until 1935. This means no operating experience is forth-coming as yet, however, an description of this structure is of interest as it is an example of the direction followed in Germany by the development of concrete barrage construction.

The wall is 47 m high and 172 m long, and is the first concrete dam designed in Germany without a curved ground plan. The thickness of the crown — 2.0 m — is remarkably small.

The concrete was made of crushed granite porphyry and diabas rock which had been carefully selected and which were mixed so as to obtain satisfactory granulation (Fig. 2) with 200 kg/m³ cement for the core wall and 300 kg/m³ cement for on the surfaces of the downstream and water faces in thicknesses of 1.0 and 1.2 m respectively. Steel lining was used for both sides.

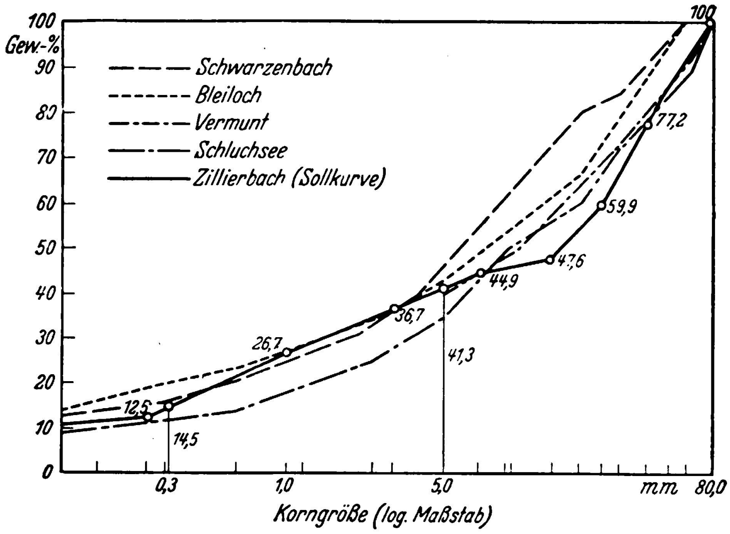

Fig. 2.

Comparison of sieving curves (Fuller curves) of recent barrages, including of binding agents (cements).

Korngröße (log. Maßstab = grain size (log. scale)

Gew. — % = weight in %.

Zillierbach(Sollkurve) = Zillierbach (ideal)

Enough water was added to produce a plastic concrete which could be easily mixed. This meant an addition of 160 to 170 litres of water per m³ of concrete, corresponding to a water cement ratio of 0.8 to 0.85 in the case of the core cement. At first a trass portland cement having a 30 per cent trass content was employed and later on a similar grade of blast furnace concrete. The concrete was conveyed to the moulds by tipping wagons which poured the material into semi-circular gutters and into Y-distribution pieces placed on a steep incline, but most of the concrete (and all the facing concrete) was poured in by in trolleys moved by rotary tower cranes. Inside the moulds the soft concrete was well tamped and stirred so as to produce a homogeneous mass.

The expansion joints of this dam are spaced at intervals of only 12 m. The water face is drained by very porous cement piping placed horizontally.

In this latest example of a German concrete dam the outer surfaces have been dealt with so as to simplify the construction and reduce its cost, while simultaneously improving the quality of the concrete from the point of view of impermeability and resistance to atmospheric action.

The latest examples in Germany of concrete barrages are the Hohenwarte dam below the Saale Valley dam and the Lütsche-Valley dam near Oberhof in Thuringia both of which are under construction.

The *Hohenwarte Valley* dam is designed to be 75 m high above the base of the wall and its top length will be 450 m. The binding agent selected is a mixture having a 60 per cent. content of trass Portland cement 40/60 and 40 per cent Thurament, both together being 285 kg/m³ of ready concrete. Granite with a maximum mesh of 100 mm, is used as aggregate. The concrete was of plastic nature and transported by cable cranes. The installation of cooling arrangement in the concrete is intended so that the heat set free during the setting process can be dispersed. The concreting work had not started at time of writing this report.

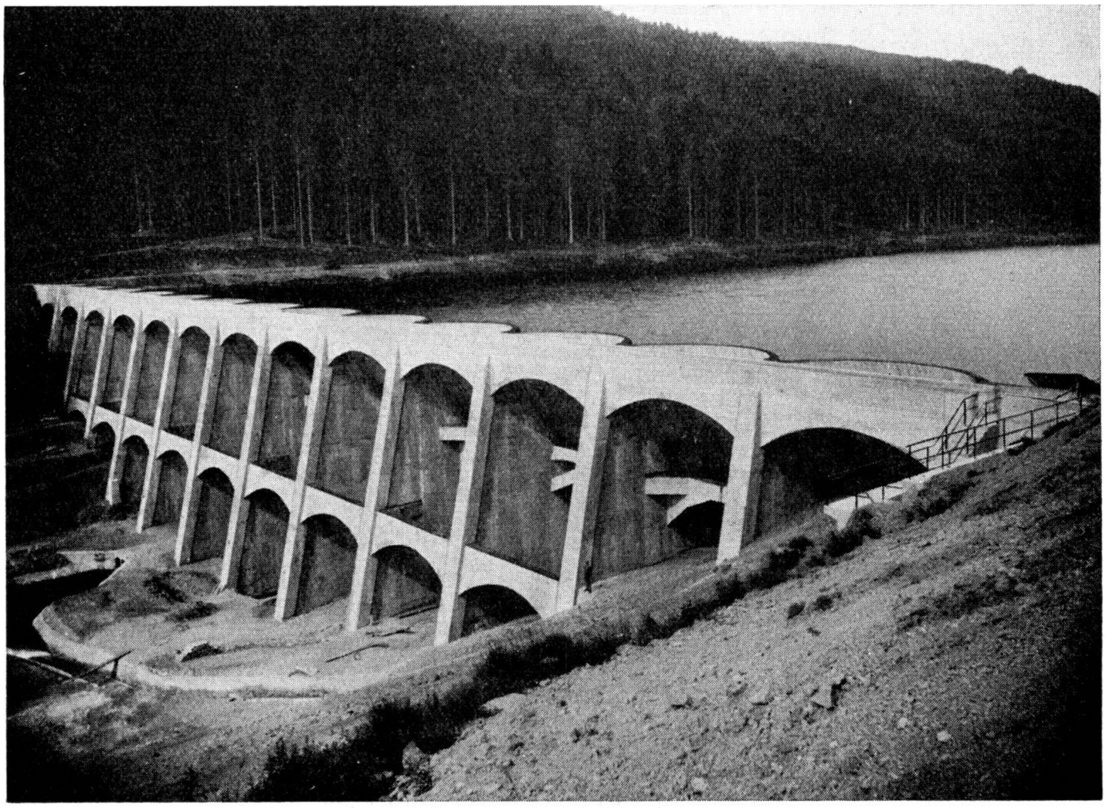

Fig. 3.
Linach barrage near Vöhrenbach

The outer faces of the wall will not be plastered or painted, as the concrete to be used will itself be sufficiently watertight. In order to remove the seepage a draining system will be provided behind the upstream face.

The *Lütsche Valley* dam is 35 m high from base of the wall to its crown, the latter is 210 m long. Portland cement alone will be used as binder when making the concrete and there will be no addition of a hydraulic binder such a trass or Thurament. The cement content for the core concrete will be 240 kg/m³, while for the facing concrete on the water and downstream faces, which, will be 1 m thick, 300 kg/m³ will be used. The aggregate used will be broken porphyry with a mesh of 70 mm. In this case, just as for the Hohenwarte Valley dam, the concrete will be transported in the form of plastic concrete with a cable crane and then made more compact by tamping and rodding.

Apart from the facing concrete referred to above, the outer surfaces will not be subjected to any other treatment to render them more watertight. The seepage will be collected by a system of drain pipes placed behind the water face.

The *Linach Valley* dam at *Vöhrenbach* (Baden Black Forest) (Fig. 3) ist the only dam in Germany built with buttness piers (with rows of arching) and in reinforced concrete. It is made of plastic tamped concrete of a composition in keeping with its closely spaced reinforcement. The upstream face of the arching has a layer of gunite rendering and several protective coats of paint.

The whole structure is watertight and does not appear to be defective in any way. If this style of construction has not been much in favour in Germany heretofore, no doubt it is due to the fact that it is an expensive method and building is complicated, so that little saving can be effected with it.

2. Earthen dams with concrete and concrete core walls.

Later on it was found that the rolled stone and earthwork barrages with watertight core walls, a few examples of which were first made in North America, enabled a saving in cost and this style was therefore developed and a number of these dams have been built quite recently.

Fig. 4.

Sorpe barrage, cross section (see Deutsche Wasserwirtschaft, march 1932, p. 42, fig. 1).

The *Sorpe Valley* dam (Fig. 4) in the basin of the Ruhr and the two Harz Valley dams at *Söse* and in the *Oder-Valley*, furthermore the *Kall Valley* dam (Fig. 5), not completed until 1935, are built according to the original design of this type of barrage. The slender core wall is subdivided by expansion joints into blocks of 24 (in the case of Sorpe) to 20 and 15 m. (Kall Valley dam.) It appeared that wider spacing was permissible than in the case of walls without earthwork, as the core walls are embedded in the soil.

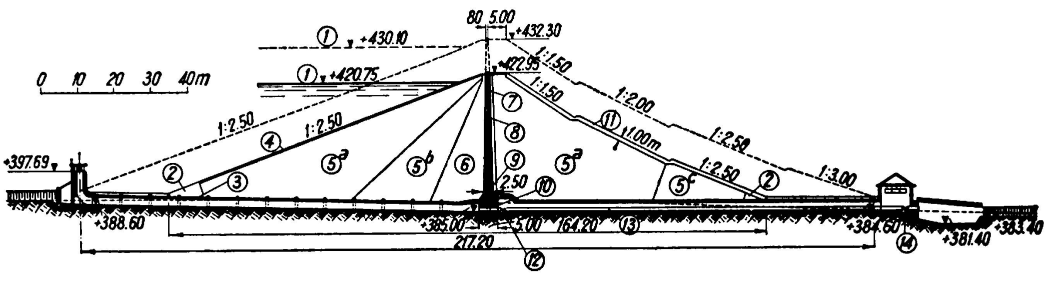

Fig. 5.

Kalltal barrage, cross section through scour outlet.

1) Flood water overflow.
2) Rubble stone packing.
3) Rock.
4) Stone pitching 0.60 m.
5a) Stone deposit coarse.
5b) Stone deposit fine.
5c) Stone deposit very coarse.
6) Deteriorated clay.
7) Metal.
8) Concrete core.
9) Sliding joint.
10) Inspection passage.
11) Turf-clad earth cover.
12) Throttle valve (closes automatically if pipe fails).
13) 2 Pipes 650 and 1100 mm diam.
14) Ring valve.

The core wall of the Sorpe Valley dam is made of the following ingredients calculated per m^3: 180 kg blast furnace cement, 60 kg artificial trass lime, 1890 kg aggregate having a grain of 0 to 60 mm with a water-cement ratio = 1,0. On the water face there is a 0.50 m thick layer of facing concrete consisting of 225 kg blast furnace cement, 75 kg trass lime and the same aggregate as above. For groating the joints between the blocks the concrete for this work received a richer mixture by adding 250 kg blast furnace cement and 75 kg trass per m^3. A facing of gunite, followed by several coats of paint, was applied to the facing concrete, while vertical drain pipes were built inside the core wall, passing out downstream at the projecting service passage at the foot of the wall. The Sorpe core wall ist excellent from the point of view of staunchness, however, it should be mentioned that so far the water has not reached its maximum height. (Full year's storage.)

The fundamental structural problem is that of giving passive earth pressure to the core wall from filling on the downstream face; this is necessary in order to strengthen the core wall so that it can resist the pressure of the remaining half of the dam and of the water pressure. The existence of this passive pressure of the earth rather leads one to assume that there is a certain displacements of the wall which, it would appear, cannot take place without a certain amount of overstressing of the material.

Attempts have been made to meet this by building channels in the neighbourhood of the foot of the wall (Söse, Oder and Kall Valley dams). These channels have been designed in the style of mere tipping or sliding grooves, or also as a combination of both. They are slightly curved and slightly inclined, and have an intermediate layer of coarse asphalt; in the case of the Kall Valley dam sliding plates have been added. So far, however, no definite opinion is available regarding the precise value of this method.[3]

Attempts are at present being made in Germany to develop core wall dams of this kind by substituting for the rigid concrete walls a more flexible steel wall and using concrete merely for the base of the wall where it joins bedrock; the concrete wall being only a few metres high.

In the *Ruhr Valley barrage* near *Schwammenauel*, the upstream coping consists of a steel wall made of horizontally arranged sheet piling; in the new *Bever Valley dam* (Rhineland) the steel wall is vertically arranged and made of corrugated sheet metal 8 mm thick welded together.

We have no information as yet as to how these dams, parts of which are still under construction meet the demand made on them.

II. *Experience and views regarding the main outstanding problems of dam construction in concrete, in Germany.*

Introductory Observation.

It is probable that decisions influenced by experience depend more on time and place in barrage construction than in any other branch of the civil engineering. Climatic, hydrological, geological and even morphological circumstances vary from one place to the next and have a marked influence on demands made on concrete,

[3] The Barrage Committee of the State Association of the German Water Supply is engaged on compiling a technical publication on the subject.

the possibilities of its composition, its manufacture and its transport. Important economic factors, such as wages, recruiting of skilled labour, cost of raw material may exert temporarily fluctuating influences. This preliminary remark refers equally to all that follows.

1. Preparation and manufacture of the concrete.

The *aggregate* had for the most part to be obtained for German barrage construction by crushing broken stone; the only difficulties encountered were that the stone quarries concerned were occasionaly inadequately equipped to meet the large demands or that the good strata had been exhausted.

The shape of the grain and its grading for size was always given the attention they deserved on account of their great influence on strength, compactness, density and weight as compared to volume of the concrete. In the past, it was the practice to use the curve for grain separation (Graf's curve) (Fig. 2), in which the largest grain is of such size as to pass through the largest mesh available, and as time went on the size of grain was increased. In the Bleiloch dam it is 60, Schluchsee and Zillierbach 80, while the specifications for the Saale Valley dam at Hohenwarte (at present under construction) laid down 100 mm.

Quite frequently rubble blocks ("plum" stones) were embedded in the plastic concrete. At Schwarzenbach the size of these was up to 2 m^3 (in practice the maximum is mostly 1.5 m^3, for large blocks the minimum size is 0.1 m^3) and the average volume ratio for these stones is 20 per cent. 30 is considered (according to Heintze)[4] the technical maximum, while the figure for the economic maximum is 25 per cent. This inclusion of stones (also introduced at Schluchsee and Schwarzenbach) reduces the need of a binder agent for the wall, increases staunchness, constancy of volume and specific weight of the concrete, and all these factors combined allow of the cross sectional dimensions being reduced, while the quality of the horizontal service channels is improved and the need for expensive dovetailing is eliminated. Plant requirements for the preparation of the aggregate and the manufacture of the concrete are also simplified, but special washing and transport apparatus become necessary. In terms of money, however, the method is advantageous. Transport of rubble stone also complicates the main building operations, considered as a whole, however, this method as applied at Schwarzenbach can be recommended. An indispensable condition in this connection is the compostion of the blocks used; their shape must be suitable and they must be sound and free from cracks. The barrages in North Germany have not as a rule complied the assumptions made.

The same principle as that underlying the use of large blocks is followed in another direction, in particular by the proposal[5] put forward by the "Austrian school", providing for the utilisation of intermittend mesh sizes with an unsteady and grading distribution. This idea was partially adopted for the first time in Germany when building the Zillierbach dam[6] (Fig. 2).

The brocken metal was graded into five sizes: 0—3, 3—7, 7—15, 15—40, 40—80 mm. After this the greater part of the 7—15 grain material was collected and

[4] Bautechnik, 26. XI. 1926.

[5] *O. Stern:* „Neue Grundlagen der Betonzusammensetzung" (New Principles for Concrete Composition), Z. Oe. I. Q. V. 1930, Issue 31/32.

[6] *Forner:* Bautechnik 29. V. 1936.

fed into a sand mill for still further desintrigation, so that a uniform sand 17 per cent resulted. The remaining requirement of sand was covered by adding ordinary pit sand brought to the site by rail. The various amounts of graded grain were put together just prior to charging the concrete mixer. The 80 mm mesh size found by preliminary experiment to be the maximum size permissible, because in the coarser mass there was a large amount of cracked pieces and these reduced the strength of the concrete.

The determining of the content of fine grain permissible called for the consideration of two opinions.

Up to the present there are two opinions as to the value fine sand as a filler. It has always been emphasised and its value was estimated so highly that where the amount of stone powder seemed inadequate, it was increased by further grinding and used as a "substitute for cement". Certain German engineers, however, had recognised long before the "impoverishing" effect of the stone powder, due to its extensive specific surface. This effect was recognised most clearly by the "Austrian school" and they studied the point thoroughly. Spindel (Vienna) has long since emphasised the injurious, loosening effect of all kinds of stone powder grain which is smaller than 5—7 times the grain diameter of the cement.[7] This application of the principle of grading the grain of the mixture: binder plus sand (d = 0,2—7 mm) has proved its value during laboratory tests for the manufacture of a dense concrete capable of withstanding inclement weather, and in particular, in connection with its application on a large scale in modern barrages built in the mountainous regions of Austria (Spullersee: 2 walls at over 1800 m level; put into commission in 1925, and Vermunt dam at over 1700 m level)[8].

Binding material. The standard requirements concerning selection and amount of the bindung material to be used in German barrage construction with its comparatively low height of retaining wall call mainly for constancy of volume, staunchness, weatherproof qualities and chemical resistance, since mechanical strength is always easier to obtain (the proportions are slightly different for barrage core-walls), and that is why attempts were made originally (following on the mortar composition for quarry retaining walls of rich lime and trass concrete advocated by Intze and his colleagues) to produce as cheap a concrete as possible while ensuring good binding qualities by introducing portland cement, lime and trass. However, when building the Schwarzenbach barrage, the idea of adding lime was dropped during execution, probably because it was found unsatisfactory and required longer time for setting. From then onwards lime ceased to be used as a concrete binding material for German barrage construction.[9] On the other hand, trass alone continued to be largely used in order to improve the cement or to produce a cheaper mixture (it is known to have no binding properties when used alone). Economic success depends to a very great extent on the facilities for transport to the districts where trass is found (Rhineland and Bavaria) and under the most fovourable con-

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[7] *Spindel:* Wasserdichter und beständiger Beton für Sperrmauern (Watertight and consistent concrete for retaining walls). B. & E. 5. X. 1932. Also Tonindustriezeitung 1913, No. 66, and Wasserwirtschaft, Vienna, 1933, No. 17/19 and 1935, No. 14/15.

[8] Cp. *B. Widmann,* Berlin: Deutsche Wasserwirtschaft, 1. VII. 1935.

[9] In the allied industry of Sluice Construction, however, it is used. Cp. *K. Ostendorf:* Die Bautechnik, 1927, Issue 39.

ditions such success is but moderate. With reference to improving the quality of concrete, laboratory experiments have proved that increased ductility and tensile strength of the mortar for heavy retaining walls are not decisive factors. The expansion of the concrete is increased by adding trass aggregate, the contraction is not reduced, indeed it is sometimes increased as a result of the increased requirement of water added to the cement-trass concrete. Opinions are divided concerning the diminishing of the setting heat by adding trass aggregate. It is generally conceded that trass has the valuable property of binding the excess lime in the cement and rendering the concrete more plastic so that it can be worked more easily.

There is no uniform practice in German barrage construction with regard to the addition of trass (even where the transport conditions are similar). When building the Bleiloch Valley dam an artificial substitute for trass — powder forming part of basic blast furnace slag — was used as »Thurament«.

The preliminary mixture of the binder which is necessary when using trass and similar material is being increasingly replaced by producing commercially trass-portland cement (Trapo) which has property of improving the concrete.

Where river water has injurious effects on the wall (very soft water) *blast furnace cement* was used on various occasions (Schluchsee, Schwarza) and the results so far achieved were found to be very satisfactory. As a matter of fact the seepage through the walls of the Schluchsee dam does contain a considerable amount of lime, however, as experiments have not yet been concluded, no final verdict can be expressed.

Alumina cement was used for patching and facing a small retaining wall in the southern parts of the Black Forest; this wall was built of portland cement and had been damaged by the soft water attacking it for a period of four years. Before long, however, signs of expansion appeared (continous scaling). Meanwhile certain scientific investigations have confirmed that the volume of alumina cement does not remain constant in water.

Recent requirements concerning fineness of grain in binding material have led to the tightening up of regulations so that the 900-mesh sieve has now been eliminated in favour of the 3600-mesh. It is pretty certain that this improvement of the binder with an appropriate limiting of the finest grain in the aggregate would lead to the manufacture of a more compact and weatherproof mortar and so produce better concreted surfaces.

Admixture of water. If too much water is added this has the bad effect of reducing crack resistance and density of the cast concrete and this fact was soon recognised by the German barrage builders.

The general practice since the construction of the Schluchsee and Schwarza dams, and including these has been to use only concrete of "soft" (plastic) composition; in this connection, however, there are still divergencies of opinion when gauging what in practice is the best content of water according to the wide margin offered by the alternative possibilities of using cast concrete or moist tamped concrete. When tenders were recently invited for a project the specification laid down a soft concrete with a flow in the channels of at least 27^0 incline (1:2), however, one of the groups of German engineers holds the view that the water content should be reduced as far as is compatible with the other building conditions and also that tamping should be carried out in moderation. These engineers applied these latter principles when building the Vermunt dam in the Austrian mountains, and they were very successful in their application of concrete con struction with mixtures of "very moist" core having a tensile strength of 150 kg/m³ and facing concrete which was "sufficiently plastic for tamping purposes" and had a tensile strength of 300 kg/m³. In spite of the various opinions at present extant, there is agreement that the stiffness of the concrete should no longer be governed by the design of the mixer, but that the mixer should depend on the various building requirements prescribing the most suitable degree of stiffness.

Mixing and pouring. For some time past the mixing process has been automatic for dam construction in Germany, and if necessary adjustable, weighing and measuring appliances being specified for binding, aggregate and water.[10] Continously working mixers are frequently prohibited. The time for mixing is restricted as far as possible. When constructing the Zillierbach dam the period prescribed was only

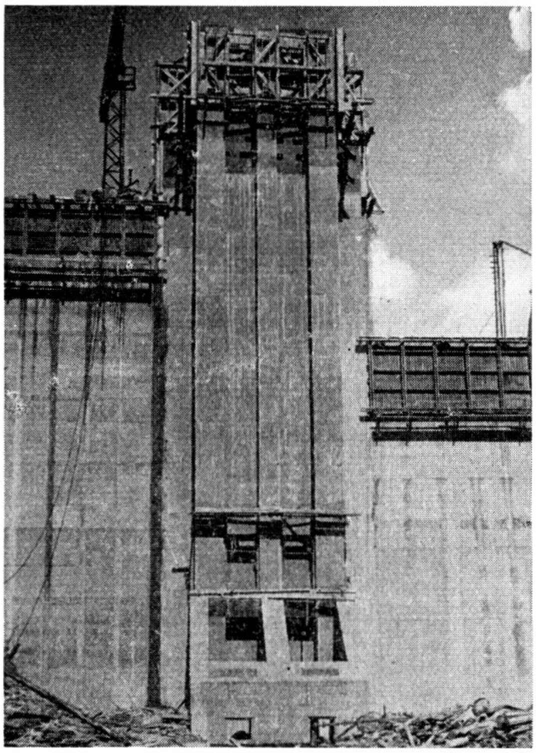

Fig. 6.
Zillierbach barrage.
Downstream face.

$^3/_4$ to one minute (total time of operation 3 minutes); the concrete produced was excellent from every point of view (Fig. 6, Zillierbach dam, seen from downstream). Nowadays the mixing plant and the dam being erected are connected by cable railways (Schwarzenbach dam and again recently the dams being erected at Hohenwarte and Lütsche) or by trolleys and conveyors, which are constructed on piers or run along the future top of the wall (Bleiloch[11] Zillierbach), or else by adjustable rotating lifts placed on the downstream face at the foot of the dam, in connection with which short channels or conveying belts are used (Vermunt[12]). At Zillierbach rotary tower cranes are employed. It is impossible to go fully into the very varied

[10] *O. Graf:* Bautechnik, 10. V. 1929.

[11] *W. Kesselheim:* Bauingenieur, 1932, Issue 13/16.

[12] *Habild:* Z. V. D. I., 20. VI. 1931, and *Widmann:* Deutsche Wasserwirtschaft, 1935, Issue 7.

and comprehensive means offered in this respect, however, we would just mention as particularly interesting the use of vertically articulated pipes on the service bridge of the Bleiloch Valley dam which is situated at a good height. In this case, where there was a free fall of 40 m, the danger of the concrete demixing was absolutely prevented by placing baffles on the inside, these acting as gravity mixers. The pipes fed distribution appliances of two to three branches and fixed to the working plattforms (Fig. 7).

So far the *concrete pump* has not been used in dam construction in Germany, but it has been successfully applied in connection with other concrete constructions in which a maximum mesh up to 80 mm was used[13]. The amount of water added had to be such that the concrete poured out the end of the main pipe in a "plastic" state. Horizontal conveying distance of 250 m was easily attained.

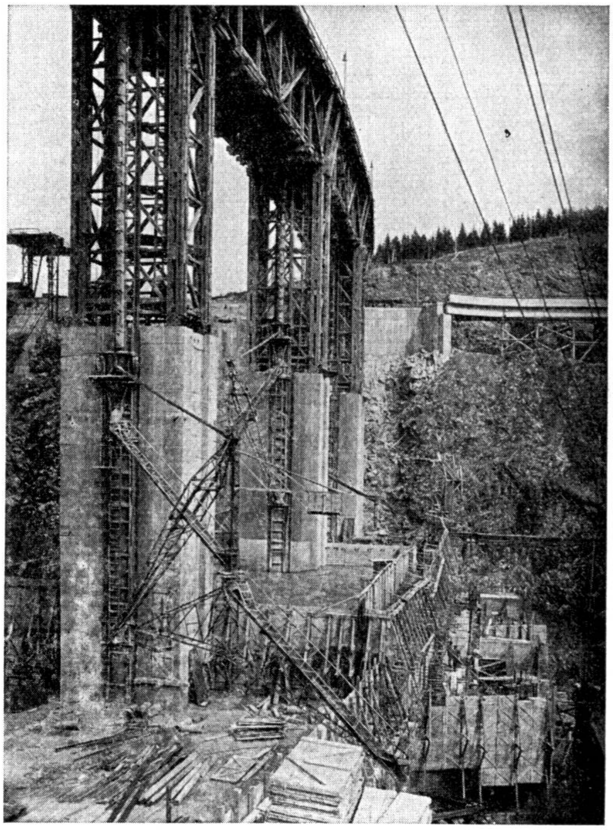

Fig. 7.
Saaletal barrage. Concrete pouring plant.

The output of work was considerably increased with these modern appliances and material. The monthly output at the Bleiloch dam, for instance (210,000 m^3 of concrete) was (incl. erection of the power house) 29,600 m^3; the daily peak figure was 1540 m^3 (two shifts working nine hours). In the case of the Vermunt dam (145,000 m^3 of tamped concrete) the monthly output reached the figure of 28,600 m^3 with a daily peak of 1960 m^3 (20 working hours).

Block arrangement, dovetailing and height of cast blocks are treated in Germany much the same as in other countries. It is interesting to note that experience has shown that absolutely rectangular groundplan dovetailing for the expansion joints

[13] *W. Kesselheim:* Bauingenieur, 1932, Issue 13/16.

occasionally leads to oblique tearing (shear) at the corners. (This was noted on the downstream surface where these perpendicular corners project.) Trapeze shaped form and other dovetailing has frequently been recommended and we should like to support that view.

The distances between the permanent *expansion joints* have been reduced from 30 and 25 m (Agger, Schwarzenbach, Bleiloch) to lower figures (Schluchsee 15,5 to 12; Schwarza 20 to 10; Zillierbach 12 m). Definite cracks were observed in the Agger and the Bleiloch dams. On account of the facing on both sides of the Schwarzenbach dam, it ist not possible to state definitely whether cracks have formed or whether the beneficial effects of the insertion of plums (20 per cent reduction of concrete) has prevented their formation.

At Schluchsee it was found that expansion joints which did not extend as far as the foot of the masonry subsequently reached that point by cracking. It is interesting to note that the cracks in the Agger Valley dam (Fig. 8) started at the

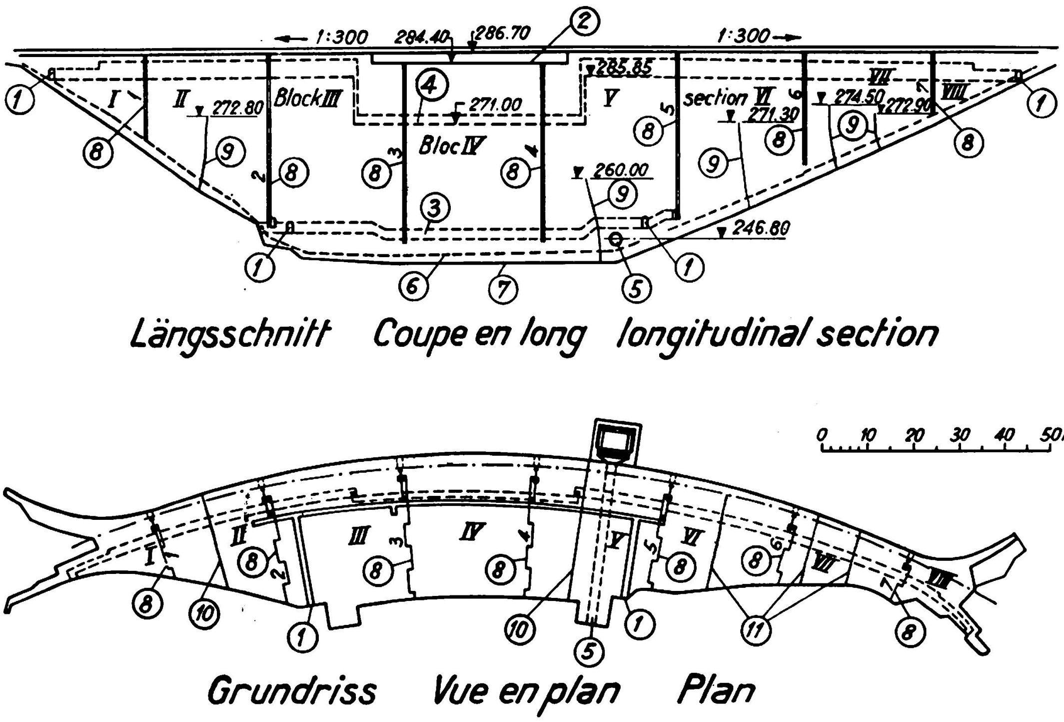

Fig. 8.

Aggertal barrage, cracks and joints.

1) Entrance to gallery.
2) Overflow.
3) Inspection gallery.
4) Upper Inspection gallery.
5) Outlet.
6) Rock surface.
7) Rock bottom.
8) Joint.
9) Crack.
10) Observed line of crack.
11) Probable line of crack.

base but did not reach the top. This phenomenon is not in keeping with the theory of crack formation in straight walls and is probably caused by the curved ground plan arrangement of the Agger dam and the increased heating and slower liberation of heat of the heavy lower part of the wall. Another point worth mentioning, although it is not easy to explain it, is that cracks seem to start mostly in hollow parts of the structure and in passages which are at right angles to the axis of the wall (Dreiläger Valley dam). In this connection we would mention that several of the modern German rubble-stone walls have cracks and other defects producing leakage[14]). These walls, with one exception, are not provided with any special protective means (joints) beyond the curved ground plan.

Lack of space prevents our dealing fully with the problem of making the expansion joints leakproof. As a matter of fact this is done much along the same lines as in other countries.

Sheet copper and moulded asphalt, commonly used to make joints staunch, was sometimes inserted in the shape of a lyre and sometimes in Z-shape (Schluchsee). A second packing device was often added in the shape of a vertical reinforced concrete tie of a dovetail section. Difficulties often arose when inserting these copper plates, with the result that the surrounding "high grade" concrete turned out porous. The designer of the Zillierbach dam accordingly, and on the strength of his experiences in connection with that dam, suggested facilitating the insertion of the packing and the improvement of its density by adding a grooved piece (sheet metal and angle pieces) in addition to the copper plate.[15] This device appears to offer a satisfactory solution (Fig. 9). A detailed report on Expansion Joints was drawn up by Link for the World Power Conference, Washington, 1936.

Fig. 9.

Caulking joint plate and built-in box joint.
(see „Deutsche Wasserwirtschaft, Aug. 1936. Paper of Mr. Forner, Fig. 2).

Facing. It was found that the steel formwork in the Zillierbach dam had been calculated too weak because building operation progressed more quickly than had been anticipated and the accumulation of blocks proved too heavy; and also because the blast furnace cement and soft concrete, which set very slowly, set up greater lateral pressure than had been anticipated. In this dam the steel formwork was applied only to the outer faces where clean surfaces and great staunchness were imperative (Fig. 10), and this proved very successful. The surfaces of the blocks on the inside of the wall were lined with a wooden formwork (patented by the contractors) having frame dimensions of 3.3 by 3.0 m with cross beams. These proved very satisfactory, for they could quickly and easily be replaced. It was found necessary to arrange and supervise very carefully the stiffening or anchorage of the formwork, so as to get surfaces that were absolutely true to plan.

Subsequent treatment, including moist coverings, spraying, etc. are nowadays considered as very important in view of what experience has taught us. In the specifications for the new Saale Valley dam at Hohenwarte, for instance, constant watering of the faced blocks for a period of two to three months is insisted on. Arrangements for lowering the setting temperatures of the large blocks have not been applied up to the present; they will, however, in the construction of the Hohenwarte dam. Moreover, it is here projected to instal a temperature-regulating device in the concrete-mixing works, so that the concrete will be delivered throughout the building period at a constant temperature.

[14] Cp. *Ludin:* Bericht über die Außenflächen der deutschen Staumauern, Report on the outer faces of German retaining walls, World Power Conference, Washington 1936, Congress on Barrages.

[15] Deutsche Wasserwirtschaft, August 1936.

2. Surface treatment and surface facing, Protection, staunching and drainage of the concrete.

Facing of the downstream surface with natural stone has not been done excepting in the case of the Schwarzenbach, Agger Valley and Kleine Brändbach dams. Frost and weather do not seem to have had any markedly bad effects on the earlier concrete retaining walls with unfaced downstream surfaces (Schluchsee, Bleiloch). The same may be said of the upstream face; the only one that has a protective covering is the Schwarzenbach dam.

The temperature of the air varies between + 37 and — 28° C in the case of the Saale Valley dam. Thus the climatic conditions to which most of the German dams are subjected are almost as severe as those to which Alpine barrages are exposed.

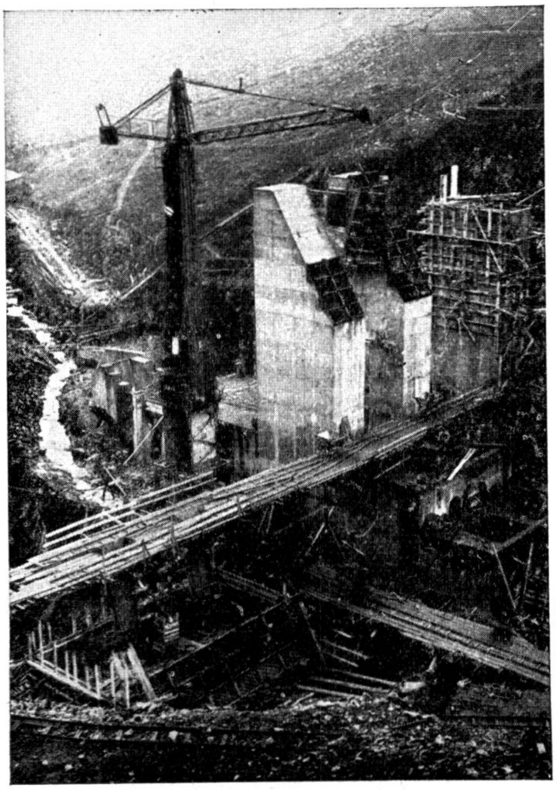

Fig. 10.
Zillierbach barrage.
Erection of steelforms.

No final decision has been reached in Germany regarding the advantage or disadvantage of using uniformly compact concrete for the whole thickness of the wall or porous coarse concrete with dense facing concrete on either face. Both the practical (list 1) and the theoretical aspect have still to be decided, however, opinion seems to be gaining ground in favour of facing concrete. Experience gained at the Bleiloch dam point to the advisability for technical reasons (crack formation) of not making the whole wall of a mixture having a high content of binder and water. (The Kriebstein retaining wall cannot be quoted as a satisfactory proof on account of its limited dimensions, while the Schwarzenbach wall is equally unsatisfactory because of its peculiar design (protective facing), based ou historical considerations.)

Facing concrete with a core having a medium to low content of binding material is more advantageous from the economic point of view.

If previous experience, in particular that of the "Austrian school", be followed, facing concrete which is practically watertight and able to withstand bad weather conditions can certainly be manufactured. Opinion is divided as to whether a further coating (gunite) should be given to the concrete. The Zillierbach Valley dam has been made without any such facing on the downstream wall, which faces a north aspect, and will serve therefore as a good test. The facing concrete of the Schluchsee and Schwarza dams were faced with gunite concrete to make them more watertight, but seepage has nevertheless occurred in small quantities, it is true, but this will have to be closely watched because the water contains dissolved lime. It is believed that the water leaks chiefly through the expansion joints. Investigation is still proceeding.

The two to three *protective coats* applied in the past to plastering or to facing concrete, mainly to resist the effects of storage water and to fill up interstices have mostly proved unsatisfatory as regards withstanding bad weather.

Recently various products have been placed on the market which appear to answer the purpose better. For instance, there is a (patented) plaster made of asphalt emulsion, asbestos fibre and sand which has been used for the rubble-stone wall at Neunzehnhain II, near Chemnitz in Saxony; this has been applied in a 2 mm thick layer. Other experiments have also been made lately in other branches of the concrete industry, e. g. with a concrete called "Bitukret" and these experiments deserve to be carefully watched in the interest of barrage construction. This material (patented) which is loosely applied is a mixture of cement, sand and diluted bituminous emulsion called "Tunol", which is stated to offer the following advantages: absolute resistance to saline agents, acids, etc., good adhesion to concrete or to walls and brickwork, in particular when the basic material is moist, and further, resistance to frost, heat and mechanical stresses.

Although the concrete surfaces are protected above all from the effects of water by the compactness of the concrete itself, it would seem very important, particularly where water exerts a specific wearing action, to apply some superficial coating which can resist chemical action. Bituminous products of the kind mentioned above may have the qualities desired. So far it has not been considered necessary in Germany to take measures which are as drastic and as costly as *steel plate facing*.

The facing concrete on the water face was generally applied in a uniform thickness, but thicker than on the downstream face (for instance, cement: 275 and 300 kg/m^3 and 0.75 to 1.00 m on the downstream face and 1.2 to 1.5 m on the upstream face) at Schluchsee, Schwarza and Zillierbach.

The facing concrete was applied at the same time as the core concrete without any intermediate formwork, unless perhaps drawn sheet metal, so that irregular dovetailing and a perfect grip was ensured for both kinds of concrete. No difficulties arose in this connection.

Draining. Besides the draining of the base of the wall, which is so important for static reasons, most German retaining walls are also provided with a drainage system on the pressure face. This is effected by means of a vertical system of collecting pipes (drains) generally placed at intervals of 1.5 to $\sim$ 4.0 and situated behind the water face of the wall. The seepage caught in this way is led to the service passages, which latter are general nowadays, and from there the water escapes into the open. The arrangement of the collecting pipes is suited to the concrete structure, mostly as near the horizontal as possible (instead of vertically as used to be the practice) and they often meet in the shafts of the expansion joints (see below). Instead of ordinary earthen or cement pipes (whose joints are left unpacked) the custom nowadays is to use blocks of coarse pored concrete hollowed out to resemble pipes of 10 cm diameter, or similar concrete pipes, which are protected by a covering of newspaper before the cement batch is poured over them when concreting takes place. These pipes are spaced at intervals of 1.5 and ∾ 5 m.

No internal drainage was provided for the Agger Valley dam, and this would appear justified when using porous core concrete covered with thoroughly compact facing concrete, as the core concrete can do the work of the collecting pipes provided it is properly drained by a few collecting pipes in a nearly horizontal position or provided the service passages are so drained.

The *drainage* of the *top of the wall* and the process of making it *watertight* should receive closer attention in view of some unsatisfactory experiences. Reports have been received that on the downstream face of the Agger dam water trickled down behind the stone facing during the day and that the torcrete plastering on both downstream and water faces of the Schwarzenbach dam suffered from moisture with the result that damaged was later caused by frost.

It was not necessary to supplement the *watertight linings* in any of the dams except at Schluchsee and Schwarza, where further cement was poured into the interstices of the expansion joints, but not with entire success.

3. Attendance and inspection.

In order to be able to watch the heat distribution and changes of volume on the inside of the wall at the Bleiloch dam, 39 telemeters were built in, and subsequently 30 at the Schluchsee dam. A provisional report has been drawn up giving the measurements recorded[16]; these are not very different from the results obtained with dams in other countries.

The *movement* of certain parts of the walls, in particular the tops, have been systematically observed in Germany (since the time of *Intze*) by means of simple apparatus. Lately trigonometrical precision measurements have also been made.[17] The concession archives of Baden contain repeated mention of surveys carried out on these lines and the results are always entered in the barrage records. (This procedure has now been introduced all over Germany.)

Arrangements for observing the pressure of the seepage and of the leakage were made a long time ago and this observation is being carefully carried out. It is limited to the base of the wall, as experience has shown that in the case of rubble-stone walls there is no apparent water pressure provided the usual measures for preventing leakage and for draining the walls are applied. On the other hand, basic water pressure is nearly always to be found at a height dependent on the height of the reservoir. In no case did this lead to any unusual phenomena. Circumstantial reports have been drawn up concerning the retaining walls of the Oester, the Eder and the Möhne.

The design and construction of dams are subject to strict State control and the regulations governing design, construction and operation of dams were laid down in a revised form a few years ago. These instructions have proved exceedingly satisfactory.

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[16] *Probst:* Deutsche Wasserwirtschaft, 1932, Part 7/8.

[17] Report by *Walther* in Bauingenieur, 5. III. 1927.

Table 1a. Concrete Barrages in Germany.

No.	Built in	Place, Water River	Height of dam-head above Sea-level m	Foundation m	River-bed m	Length in m	Radius in m	Up-stream face looks	Thickness of dam on top	on river-bed	Slope of face vert.: horiz. = 1: ..... downst.	upst.
1	1909—1911	Aachen *Dreiläger*	393.00	89.5	32	300	350	W.	3.00	29.00	0.591	0.10
2	1922—1926	Forbach *Schwarzenbach*	670 00	67	50	400	400	S. E.	6.00	39.00	0.711	0.031
3	1927—1928	Oberberg *Agger*	286.50	45	43	225	225	S.	6.50	29.00	0.647	0.05
4	1927—1929	Kriebstein *Zschopau* (Saxony)	214.25	30	23	230	225	N. N. E.	4.00	17.30	0.848	0.04
5	1929—1932	Seebrugg *Schluchsee* and Schwarza	931.50	45	35	240	straight with break on centre	W.S.W.	3.70	27.00	0.72	0.03
6	1928—1931	Schwarzabruch *Schwarza*	724.75	43	33	158	140	S. W.	3.70	25.50	0.72	0.03
7	1926—1932	Saalburg *Saale* on kl. Bleiloch	412.00	70	60	215	300	N. N. E.	6.70	46.15	0.69	0.02
8	1934—1935	Wernigerode *Zillierbach*	473.00	47	39	172.5	∞	N.	2.00	26.52	0.63	0.05
9	1935—	Gräfenrode *Lütsche*	583.50	35	25.10	210			3.80	16.75	0.71	
10	1935—	Hohenwarte *Saale*	306.40	75	67.20	450	400	W.	7.20	49.00	0.71	0 02

Table 1b. Concrete Barrages in Germany.

No.	Expansion joints: Extent m	Expansion joints: Interval m	Facing of upstream surface: Plastering: thickness in mm	Protective coating mm	Protective covering	Concrete facing: Thickness mm	Concrete facing: Cement kg/m³	Drainage of dam	Facing of downstream surface: Natural stone	Concrete facing: Thickness m	Concrete facing: Cement kg/m³
1	unknown	1 vertical joint left	unknown	affired with Siderosthen	yes	—	—	yes	yes	—	—
2	mid-dam 57,00 m high	centre block 36 m adj. 27 and 25 m	Gunite 25	from 606 — 630 three-fold cardboard layers under covering	yes	—	—	yes horizontal	yes	—	—
3	from top to 3 m above base	30.00	—	—	—	2.0—2.50	275 kg H. G. C. + 83 kg Tr.	—	yes	—	—
4	from top to 1,5 m above base	20—25	Gunite with smoothened surface	Inertol 3 applications	—	—	—	yes	—	—	—
5	from top to base	12—15.50	Gunite 25	Inertol 2 applications	—	1.50	275 H. G. C.	yes	—	0.75	275 H. G. C.
6	from top to base	10—20	Gunite 25	Inertol 2 applications	—	1.50	300	yes	—	1.00 planed	300 wood casing
7	from top to base	25	—	—	—	—	—	yes	—	—	—
8	from top to base	12	—	2 coats up to within 8 m of top	—	1.20	300	yes	—	1.00	300
9	from top to base	12—13	—	—	—	1.00	300	yes	—	1.00	300
10	from top to base	15	—	—	—	—	—	yes	—	—	—

Table 1c. Concrete Barrages in Germany,

No.	Experience under Service Conditions							Supplementary and Repair Work done
	Upstream face		Downstream face					
	Cracks	Damage by frost	Cracks	Damp patches	Leakage	Incrustation	Damage by frost	
1	2 vertical	—	2 vertical	few	from work joints	yes	Top facing of dam	New surfacing of dam-top with chips and bituminous emulsion
2	—	in Gunite plastering	—	—	—	—	—	Gunite plastering repaired below coping; otherwise nothing noteworthy
3	1—2 hair cracks in each block	slight	1—2 hair cracks in each block	in winter a few on top of dam	yes	—	—	—
4	—	Flaking	—	—	—	—	Flaking	
5	—	in Gunite	—	Dampness in all joints	yes	—	—	Cement injections
6	—	—	—	—	yes	yes	—	Cement injections
7	4 large	—	4 large	—	yes	—	—	4 shrinkage cracks caulked
8	—	No reports available beg. 1936						
9	—	still under construction						
10	—	still under construction						

Table 2. Principal Materials used in German Concrete Barrage Construction.

No	Name of Barrage	Quantity of Concrete in m^3	Type of Concrete: G. B. [1]	Type of Concrete: Pl. or W.B. [2]	Type of Concrete: St. B [3]	Binding: Cement kg/m^3	Binding: H.-G. C. kg/m^3	Binding: Aggregates kg/m^3	Aggregates: Type of Stone	Aggregates: Granulation in mm	Mixtures: kg/m^3 or parts	Admixture of water l/m^3	Specific weight: γ_B t/m^3
1	Dreiläger . . .	72 000	—	—	yes		—	Trass and lime	Quarzite		$1/2$ C. $2^1/_2$ Tr. $1^1/_2$ L. 7 Sd. 9 M.		—
2	Schwarzenbach .	297 000 with 20% "plum" stones	yes	—	—		—	Trass and lime			C. L. Tr. Sd. M. 1.0 0 5 1.0 4 6 units 1.1 0.4 0.8 4 6 „ 1.0 0 0.6 5 7.5 „ 1.0 0 0.44 4.6 6 9 „	250	2.25
3	Agger	100 000	—	yes	—	—	200 175	60 Trass 45 „	Graywacke	0—80	Aggregate 1850	212	2.33
4	Zschopau . . . near Kriebstein	82 000	yes	—	—	frist 200 then 180	—	Trass 75 65		0—60	Aggregate 1680	330	2.3
5	Schluchsee . . .	124 000	—	yes	—	—	up to 22 m below surface 200 above 22 175	—	Granite		Aggregate 2040	160—180	2.4
6	Schwarza . . .	52 000	—	yes	—	220	—	—	Granite		Aggregate 1920	160—180	2.31
7	Saale . . . . . on kl. Bleiloch	210 000	yes	—	—	b. 118 m. 105 t. 87	—	Thurament b 229 m. 205 t. 169		0—60	0—7 7—30 30—60 mm P.C. Thur. aggregates b 118 229 804 689 459 m. 105 205 859 687 459 t. 87 169 940 678 453	236—243	2.45
8	Zillierbach . . .	58 500	—	yes	—	200	—	—	Diabas and Porphyr	0—80		Wat-Cemt ratio 160—170	2.4
9	Lütsche	38 000	—	yes	—	Core 240 Facing (300)	—	—		0—70			
10	Hohenwarte . .	450 000	—	yes	—	Trapo (total 285)		Thurament	Granite	0—100	(0.6 Trapo + 0.4 Thur.) : 2.48 Sd. 0—7 mm : 1.21 chips, 7—30 mm : 1.54 metal, 30—60 mm : 14.8 metal 60—100 mm	185—190	

[1] Wet liquid concrete. [2] Plastic Concrete. [3] Rammed moist.

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Summary.

Modern dams made of concrete were first built in Germany in 1922. Originally cast concrete was used, but this was soon dropped in favour of soft concrete (plastic concrete). Meanwhile a dam built by German engineers in the Austrian Alps and made of tamped plastic concrete has found many advocates in Germany.

With regard to making the dams watertight, two schools of thought exist. One favours the construction of walls made of a uniformly compact mixture of concrete (with amounts of binding aggregate varying solely for two to three zones of height). The other opinion recommends making the wall core of concrete which is not absolutely impervious and of facing the water and downstream sides with additional plastering about 0,75 to $\sim$ 1.5 thick and consisting of high grade compact concrete, with an additional high grade coat, generally applied by spraying the downstream face.

Facings of natural stone were used only for the first three concrete dams; recently this practice has been dropped without any disadvantage to the barrages.

The retaining wall is mostly fitted with an arrangement of drainage pipes inserted in the wall.

A proper selection of size of grain for the aggregate of concrete is considered very important in order to obtain the right consistency of the concrete. The trend at present is to develop as far as possible the principle of intermittend (grading), and this is being done in various directions.

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