PRELIMINARY REVIEW OF CHARACTERISTIC FEATURES OF THE ICE PRODUCTION IN THJORSA RIVER SYSTEM WHEN UTILIZATION OF WATER POWER IS BEING PLANNED.

Reykjavík, 12.March 1965

Preliminary review of characteristic features of the ice production in Thjórsá river system when utilization of water power is being planned.

Director General Jakob Gíslason has found it desirable that we should write down in a memorandum such observations and considerations which might be of use to the model experiments which will be performed at the River and Harbour Research Laboratory in Trondheim, and likewise have relevance to the actual Burfell project. We take the reservation that this P.M. can only give a provisional analysis.

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A. Description of Tungnaá and Thjorsá in the river section between Hald and Tröllkonuhlaup, with ice production characteristics.

The area of Tungnaá from Hald and downstream to the confluence with Upper Thjorsa is about 2-3 km^2, the distance is 5 km and the average slope 2,4 m/km. The ice production in this area is of special importance not only for the section itself, but even so for the ice conditions of the next area, the section of Thjorsa from Tangafoss (the confluence with Tungnaa) to Tröllkonuhlaup. This area is about 7-8 km^2, the distance is 17 km and the average slope 3,7 m/km. Fig. 1 gives a location map of the area and a longitudinal section of the river.

The velocity of the main water flow in this area is during the winter within the interval 1-2,5 m/s and thus above the critical value of 0,6 m/s which limits the development of a normal ice sheet. In this case the surface of the river will remain open where the velocity is greater than the critical value. The heat loss during cold weather will produce individual ice crystals which may float in clusters on the surface as sludge ice, be immersed in the water stream, or produce bottom ice on the river bed e.t.c.

River parts which are getting narrow and deep will facilitate the formation of an ice carpet by compression of floating sludge ice, thus establishing an ice bridge between the river sides. The water stream will go under the floating ice bridge and carry floating ice further downstream. Such places are often not far downstream from a waterfall or a rapid, e.g. below Thjofafoss and below Tangafoss, just to mention two important sections where the formation of ice-carpet-bridges regularly occur during cold weather.

An analysis of the different types of the rather complicated dynamic ice production is given in section B of this memorandum. Illustrations are given from some situations in Thjorsa in the fotos of plates 1-5.

Plate 1 shows the field barrack near the rapids above Tangafoss, on a cold day, Dec. 12th 1964. Velocity is too great for floating sludge ice which will be immersed. Probably bottom ice is produced in the rapids. The photo from Tröllkonuhlaup shows a similar situation, but upstream of the waterfall many white patches are seen, which are small isles of ice grown up from bottom ice formations around stones on the river bed.

Plate 2. Upper photo shows remants of accumulated ice, lower photo demonstrates how sludge ice has been stopped, compressed and established an ice bridge across the river downstream of Tangafoss. The water stream is passing under the ice cover carrying within the stream immersed sludge ice and other ice remnants which have been produced higher up in river section.

<u>Plate 3.</u> Upper photo shows floating sludge ice and also land ice, which has been formed partly by bottom ice production and partly by sheet ice production when the water level has been raised. The crack might produce an ice floe of considerable size, if a sudden rise of water level should come. Lower photo shows a shallow section of the river with isles produced by bottom ice growth and accumulation of sludge ice.

<u>Plate 4</u>. Upper photo shows floating sludge ice near Klofaey and lower photo about 1 km farther downstream. The velocity of flow is 1,2 m/s, which may be considered typical for sludge ice floating on the stream.

<u>Plate 5</u>. Upper photo is showing how in turbulent water of high velocity frazil ice will be mixed into the water at any depth. Notice the remnants of accumulated ice masses (from another cold spell) with the big cracks, and the vertical ice walls on the opposite river side. Lower photo shows (see left corner) where pack ice is growing up-stream, Old ice walls are seen on the right side of the stream.

Reference is besides given to the illustrative material presented by Mr. Sigurjón Rist and Dr. Gunnar Sigurdsson.

The ice masses in Thjorsa may be loosened and set into motion by a "step burst" or by a winter flood. Such weather changes with ice jams moving downstream may occur several times during a single winter. Interesting material is presented in the typed report "Studies of ice disturbances at water gauges No. 30, 97 and 98 on the Thjorsá and Tungnaa rivers 1960-64." The daily observations of water level and discharge demonstrate how the discharges varies with the ice production, ice transport and ice accumulation.

Generally the main characteristic of the river Thjorsá is that the river is an ice producer of extraordinary dimensions. The ice masses are very much greater than those occuring in Scandinavian rivers, and comparable quantities are probably very rare in other countries as well. The problems which the planners of power plants will encounter will, however, not only arise from the magnitude of moving ice masses,but even more serious may be the change of physical qualities which accompanies the different stages of ice production, ice transportation and ice accumulation. These characteristics will be treated in section B.

B. Dynamic ice production with special reference to the conditions in Thjorsa river.

1. Formation of bottom ice and floating frazil ice (sludge ice) in a turbulent stream.

When the turbulent water stream has been cooled down to $0^{o}C$ the heat loss from a free water surface will cause a supercooling of a very thin water film which incessantly is being renewed through the turbulent motion of the water masses. A supercooled element of the surface film will move in an irregular way through the water and may just as often sweep the bottom as be moving along the surface. On the way down the supercooling of the element will decrease and a slight supercooling of the surrounding water will result.

An individual crystal will have to start at a solid nucleus and can only grow in surrounding water when the liberated heat of crystallization can pass from the crystal wall of $0^{\circ}C$ to adjacent water of lower temperature i.e. supercooled water. It ought to be emphasized that as long as the heat loss continues from the water surface there will be a stationary stability in the exchange of heat between the growing individual crystals and the surrounding supercooled water stream. An open turbulent stream carrying ice crystals with it will not attain exactly $0^{\circ}C$ through the whole water mass till the heat loss from the surface has ceased.

Evidently the chance of a crystal growth will be the greatest in the surface film, and the smallest at the bottom, where the chance will depend upon the time which the moving water film element will use on its way from surface film to bottom, i.e. upon the water velocity and the depth. The formation of bottom ice will thus be more frequent at shallow sections than at deep ones.

The number of nuclei suspended in the water may be so great (sedimentation, sand storm, snow storm) that practically all crystallization will take place in the upper layers of the water. In such cases the growth of bottom ice will become reduced or cease.

Ice crystals have a tendency to form clusters. The buoyancy will be sufficient to keep the clusters floating if the velocity of the water current is lower than a certain critical value, which according to our preliminary measurements is about 1,2 m/s.

In the uppermost strata of the water stream the floating clusters will reduce the turbulence, but the cluster will long remain as a very loose structure, growing gradually downwards in much the same manner as bottom ice is growing upwards. This demonstrates that there is some circulation of supercooled water through the interstices of the structure. The structure has very small cohesion when floating freely in the water. Measurement of the weight of ice per unit volume is difficult to perform with accuracy, but provisional measurements have given values between 0,3 and 0,4 kg/l for floating sludge ice in Thjorsá.

In the open surface areas between the clusters turbulent motion will still be effective, producing a supercooled waterfilm, elements of which will be moving through the water as mentioned above. At river sections, however, where the clusters cover practically the whole surface, a supercooling of the water stream under the floating cover will be very small. In that case a layer of bottom ice produced formerly would cease to grow, but it would still exist till the heat balance were reversed through rising air temperature.

When the water transport is illustrated by <u>stream lines</u> the following consequences will appear for the relation between surface areas covered by clusters of sludge ice and open areas between:

a. Where stream lines are <u>diverging</u>, open surface areas will be increased. In such places the supercooling will produce conditions for bottom ice production e.g. where the river is expanding. Another important case is the water surface just in front of an obstacle placed in the stream, e.g. a stone or a pillar, and similarly for the water surface just behind the obstacle. The shallow sections of Thjorsa abundantly show how blocks of stone are growing points for bottom ice which gradually may develop a comparatively strong structure around the original obstacle.

b. Where streamlines are <u>converging</u>, for instance near an obstacle the open areas will be reduced. As long as the velocity of the water is below the critical value mentioned above the chance for bottom ice production will also be reduced. When the convergence should increase the velocity above the critical value, however, the sludge ice would be immersed in the water, leaving the surface open to the production of a supercooled water film, the elements of which would follow the converging water stream which would be sweeping along the obstacle on its way. This case is of importance when the obstacle is a pillar placed in the stream.

2. <u>Compression and solidification of sludge ice. Accumulation. Ice jams. Step bursts.</u>

As mentioned above sludge ice clusters floating downstream in the surface layer has a very loose structure. However, when we fetch a portion of such sludge ice we can easily squeeze it to an ice ball which is quite similar to a snowball, such as we make from newly fallen and wettish snow. This change of qualities is mainly due to the regelation effect on the ice crystals being pressed together.

Even a slight dynamic force may strengthen a loose structure of ice. If for instance a coarse net or a series of paralled and vertical bars are placed across a shallow stream carrying frazil ice and producing supercooled water, the pressure gradient caused by the obstacle will tend to produce a more tight structure than that of floating sludge ice. Immersed ice particles arriving to the structure may be caught and effectively contribute to narrow the openings. The result may be that the openings will be closed by packed frazil ice.

In some power plants the thrash racks at the intake are some times simply removed when a cold spell causes high production of floating sludge ice and feeding of super-cooled water to the intake. By this precaution ice troubles has occasionally been avoided at such power plants, for instance at Laxá Power Plant. This method will, however, not be applicable generally.

The production of ice dams is a combined effect of super-cooling, crystal growth, frazil ice drift, dynamic compression and regelation. The result is an ice dam of a remarkable stability, and such a dam can in certain places raise the level considerably and for a short time store great volumes of water.

The different sections of Thjorsa present a series of examples of sludge ice production and accumulation. The waterfalls act as giant mixmasters, producing a soup of turbulent water, a suspension of sludge ice and disintegrated blocks, some of them coming from strand ice and some from accumulated masses of compressed sludge ice.

The section from Thjófafoss and about 7 km further downwards present during strong cold a dramatic illustration of how the ice content of this soup can build bridges of compressed sludge ice and accumulate huge masses of ice, the density of which will be about 0,6-0,7 kg/l in the kg/l uppermost layer and increasing downwards to nearly 0,9/in the lowest layer.

It is important to emphasize that compressed sludge ice is a substance which is quite different from floating sludge ice of loose structure. From accumulated ice bridges huge blocks may be broken, carried away with the stream and getting rounded, then perhaps diving under a second ice bridge, looking like a diving whale.

In the section from Tangafoss to the damsite several parts are accumulation areas. Other broad shallow parts, especially around the isles produce ice dams and cause local sheet ice production when the water level is raised, due to the frazil ice production in the main stream during a cold spell.

When the ice masses in this section are broken up by a winter flood or a step burst which carry the masses downwards, a mixture of all types of ice, sludge ice, loosened bottom ice, broken land ice, small and great ice blocks, will float with the stream. At Klofaey the stream on the right side is always open, while the stream on the left side will be covered by pack ice and sheet ice till the flood comes and sweeps the ice cover away. The flood will thus fill both branches of the river at Klofaey. The water level has according to observations risen 0,5 m when such a flood has been passing Klofaey.

C. Ice conditions to be considered for an intake dam at the projected dam site near Burfell.

The cross section of the river at the projected damsite has a width of 350-400 m. The river bed is a very regular plane and the depth of the water under normal winter discharge is about 0,5 m. At Klofaey the two branches together have a width of about 400 m, and during a high winter flood carrying ice the water level here has risen 0,5 m. A similar rise may then be expected to occur when such a flood is passing the damsite in its present state. Further is to mention that the passage of ice during a winter flood hitherto has met no obstruction at that place, even when the transportation of ice masses from river sections was very great.

If the design of the dam could make it possible to reestablish, practically, the present cross section whenever it might be necessary, it seems rational to assume that it would be possible to pass a winter flood carrying ice masses through the open dam, without a risk of ice accumulation upside the dam, which might cause full stop of the power station for a too long time. This consideration makes it desirable to examine the alternative of building the dam from one riverside to the other.

It would further be highly desirable to reduce the open ice producing areas upstream the damsite, for instance by leading Tungnaa through Blautakvísl to Thjorsa, and by establishing a number of threshold dams in the broad Thjorsa section upstream Klofaey.

Details of such a programme might be considered later.

Reykjavík 12. March 1965

Olaf Devik　　　　Edvigs V. Kanavin

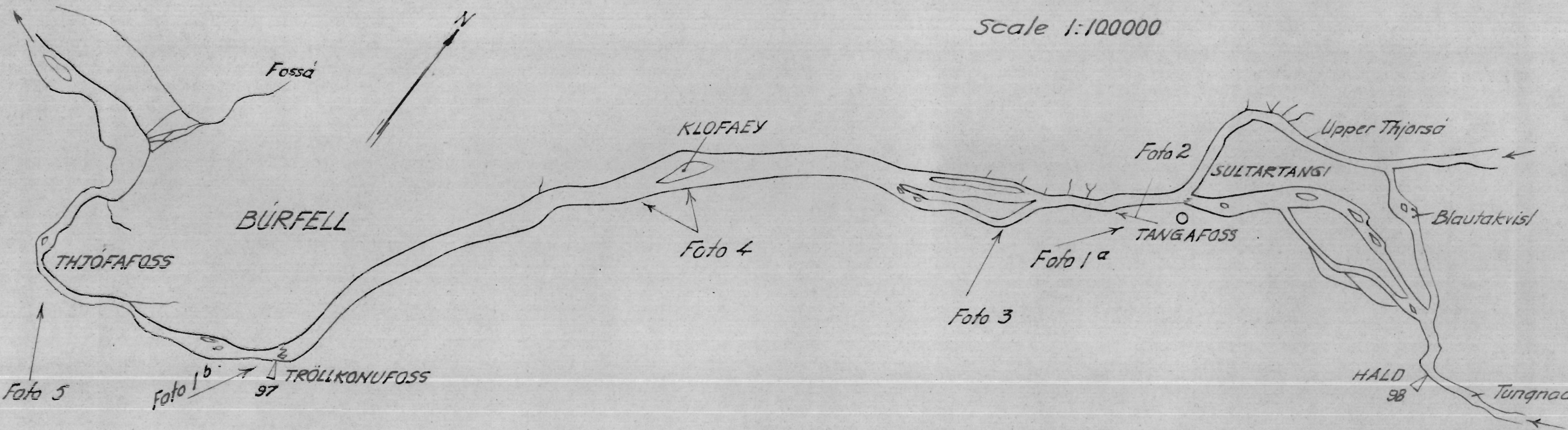
Iceland

Fig. 1

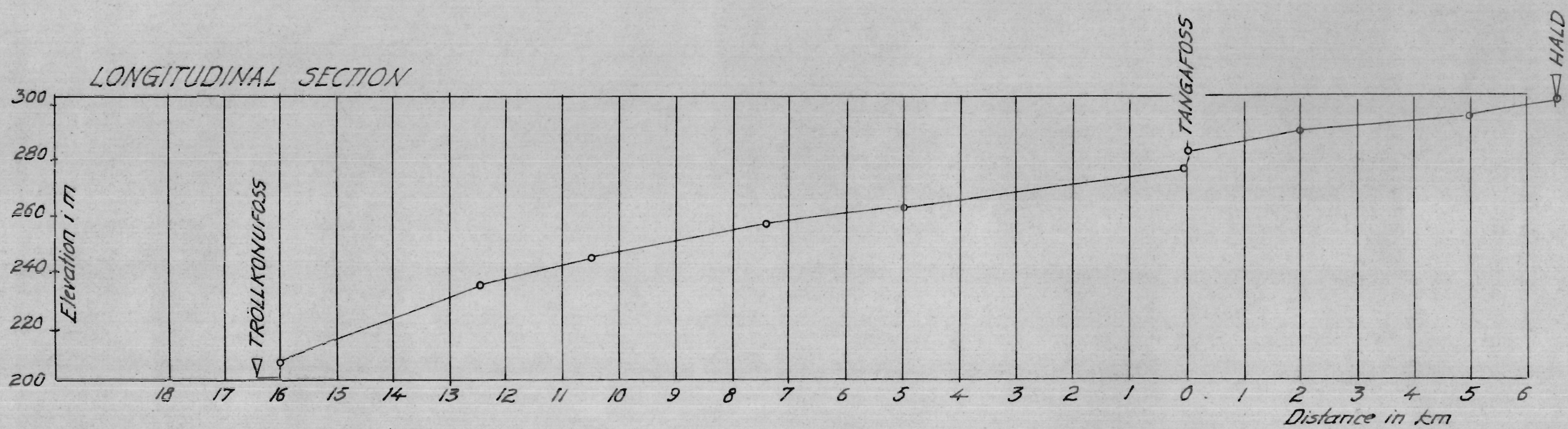
TUNGNAÁ and THJORSÁ

LOCATION MAP from section
HALD - BÚRFELL

Scale 1:100000



LONGITUDINAL SECTION



a

Tangafoss meteoralogical station

b

Tröllkonufoss gauging station

ICELAND

Thjórsá downstream of Tangafoss.

View downstream

Ice bridge, 12 Dec. 1964.

JCELAND

Thjorsá, approx. 4 km downward Tangafoss.

Floating sludge ice.

Bottom ice on the riverbed

JCELAND

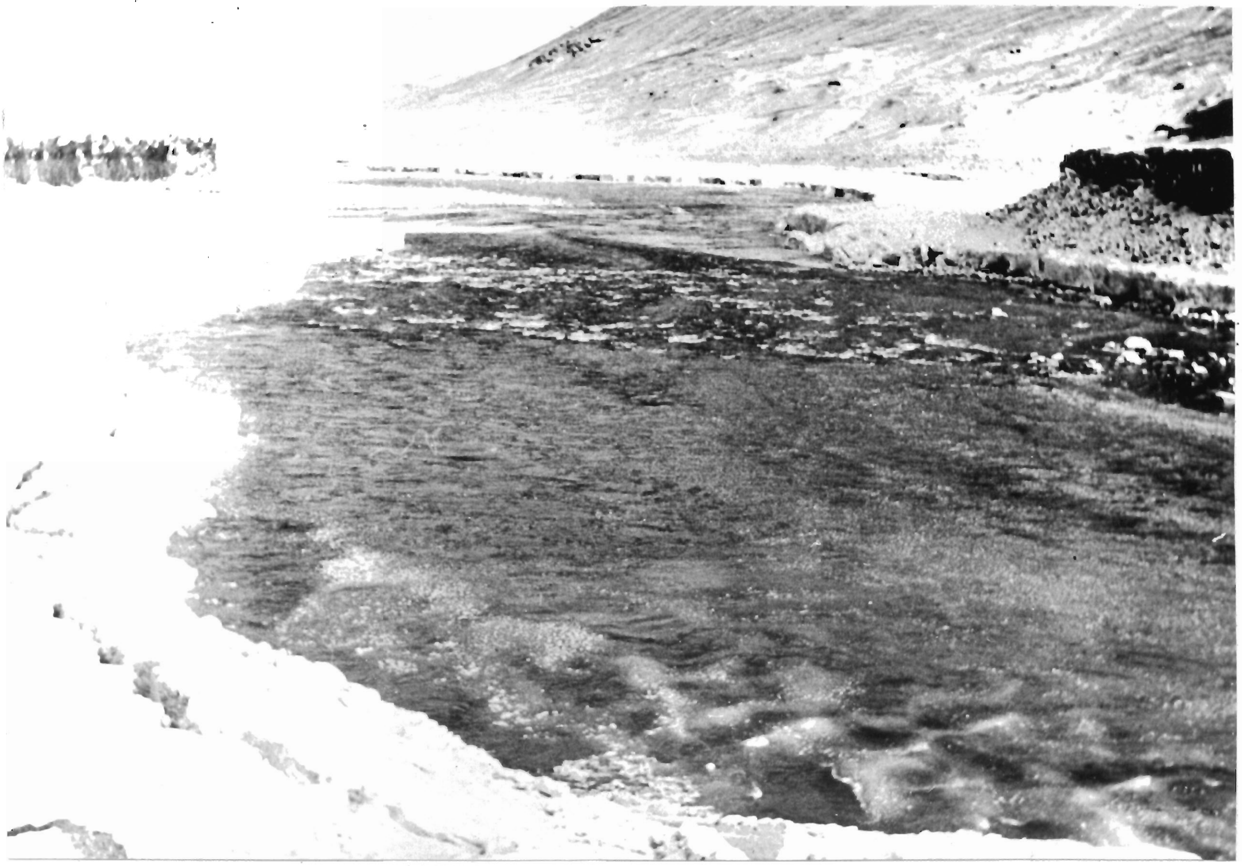
Thjorsá near Klofaey, 12 Dec. 1964

Floating sludge ice
Riverbed ca 400 m, thickness of sludge ice 20 cm

View downstream
Velocity of flow 1,2 m/s

JCELAND

Thjorsá, downward Thjofafoss, 9. Dec. 1964.



Jn turbulent water frazil ice is mixed in any depth of the river. View downstream

Pack ice cover growing up-stream.