NEW DESIGN STANDARDS FOR HYDRAULIC STRUCTURES IN THE SEISMIC ZONES OF THE USSR

by

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SYNOPSIS

A short review of the new design standards in the earthquakeproof construction of hydraulic structures enforced in the USSR of October 1, 1972, is given. The introductory part of this document is described which includes recommendations to evaluate the seismicity of the construction site, requirements in seismic geological and seismic engineering research carried out to obtain the initial data for design purposes etc. The basic principles for evaluating the seismic effect on hydraulic structures are characterized and measures to ensure their seismic stability are recommended.

INTRODUCTION

A considerable part of the territory of the USSR comprises seismic zones. About 13% of the total area of the country may be subjected to earthquakes of intensity 7,8 or 9 according to the Seismic Scale of the Institute of Terrestrial Physics, of the Academy of Sciences of the USSR /1, 2/ Fig.1 represents a map of seismic zoning of the USSR made in 1967. According to the map seismic zones are located mainly along the southern and eastern borders of the country forming a seismic belt for a total distance of 10.000 km. Recently this part of the country has become the site for large-scale hydraulic construction essential for the development of the national economy of the Republics of Caucasus and Central Asia as well as regions of Siberia and the Far East of the USSR.

At present construction of a number of major hydropower projects (Inguri, Chirkey, Nurek, Toktogul, Charvak and Sayany) with dams 170-

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300 meters high is underway in the seismic zones.

Plans are being developed for the future design and construction programmes for many other major hydro-power plants in these areas, including the Ragun station on the Vachsh, the Kurisai plant on the Naryn, the Miatlinskaya on the Sulak and the Namakhvan and the Terter cascade in Transcaucasia and some others.

Soviet hydraulic engineers are faced with many difficult problems resulting from the task of securing the safety of the aforementioned hydraulic structures, and other structures being built or designed for construction in the seismic zones.

Those problems are paid considerable attention to in the USSR.

In particular new Design Standards for Hydraulic Structures in the Seismic Zones /6/ were recently worked out and came into force since 1972. They contain general remarks, recommendations for the evaluation of the seismic design effect, and a list of the constructive measures for increasing the seismic stability of hydraulic structures.

GENERAL REMARKS

In this section the sphere of applicability of the new Standards is defined, the requirements for engineering seismological and seismogeological investigations into the construction sites of the hydroelectric projects are formulated, general rules for evaluation of the seismicity of construction sites according to the dimensions and importance of hydropower structures to be designed are given together with the principal demands for the evaluation and model investigation of the seismic stability of these structures and the requirements for constant instrumentation studies of structural vibrations during earthquakes.

The evaluation of seismicity of the construction sites with regard to geological engineering features by seismic zoning maps is permitted only for non-pressure or low-pressure hydraulic structures whose destruction would not lead to loss of life or serious damage to property.

Seismicity of the construction sites for high-head structures must be evaluated only on the basis of special seismogeological and seismic engineering investigations.

Requirements to such investigations are summed up here for the first time.

In addition to seismological studies of the construction site and obtaining of valid data for earthquake analysis of a structure, its foundation and canyon walls the following requirements are worked out for the pre-construction period:

- to establish possible zones of residual deformations in structure foundations;

- to find out specific forms of seismic danger, for instance, the possibility of sliding of large rock masses into the reservoir or upon the structure;

- to obtain data characterizing the dynamic properties of foundation soils and structural materials for earthquake stability calculations;

- to check out possible changes in the seismic behaviour of a structure due to filling up of the reservoir.

Spectral methods of earthquake stability evaluation of hydraulic structures are considered most advisable .

In the design of most important structures calculation methods using analagous earthquake accelerograms are admitted along with the seismic stability evaluation prescribed by the seismic coefficient.

The necessity of model testing conducted to define natural vibration modes and frequencies, the seismic stress-strain state and also different types and conditions of failure is formulated as a special item.

Occurrence of residual strains and structural damage (residual settlements, displacements and cracks) not endangering the safety of hydraulic structures is not excluded on condition of special engineering and economic substantiation and only in cases when the strains and the damage can be evaluated and taken into account in the design stage and removed after the earthquake by an appropriate maintenance of the structure. For the first time design of the largest high-head hydraulic structures envisages permanent instrumentation investigations into the behaviour of structures, their foundations and canyon walls during earthquakes.

EVALUATION OF THE SEISMIC DESIGN EFFECTS

In the following Section Standards and Rules to evaluate seismic inertia loads versus dead weight of structures, the added masses of water and the seismic pressure of soil are given.

As a general case seismic action is supposed to be randomly directed in space. The strength analysis of dams (except of those types in which the stress state is significantly dependent on vertical displacements, e.g. double curvature arch dams) takes into account only the horizontal component of seismic action.

The analysis of general stability of a structure also takes into account the vertical component, assuming that the two components act simultaneously. For the cases when the structure may be represented by a simple cantilever a well-known expression is recommended to determine the seismic load, S_{iK} , at a point "K" of the structure corresponding to the i^{th} mode of its natural vibrations:

$$S_{iK} = m K_s \beta_i^0 \eta_{iK} Q_K \qquad (1)$$

where: α - angle between the horizontal and the direction of the seismic action not exceeding 30°.

If the vertical and horizontal components of seismic forces are simultaneously included in the design the value of K_s in /1/ is multiplied by $\cos\alpha$

Methods to establish inertia forces in structural stability calculations and methods to determine design forces in structural strength evaluation are recommended.

In calculating the stability of structures represented as cantilevers not more than 5 natural vibration modes should be included.

If the design structure is represented as a three-dimensional body, such a number of natural vibration modes for the stability calculation should be taken that the seismic load increment from any two successive modes does not exceed 10%.

The Standards previously in force /4/ being based on the static theory of structural earthquake resistance, the influence of water medium was estimated according to Vestergaard by considering the hydrodynamic (seismic) pressure on a structure as a pressure on a solid body and by adding subsequently the resulting value of hydrodynamic pressure to that of the hydrostatic pressure.

In contrast, New Standards /6/ suggest that the effect of water inertia should be taken into account in the evaluation of natural vibration periods and seismic loads.

Therefore instructions are given to determine the associated masses of water by evaluating natural vibration modes obtained without the influence of the water medium upon structure.

The value of the associated mass of water thus received is added to the own masses of the structure, the subsequent calculations being adequate for the calculations of a standard "dry" structure.

The value of the associated mass of water depends on the depth and the geometry of the reservoir, its physical state (aeration, existence of deposits and ice, the character of the bottom and the canyon walls), the elastic properties of the structural material etc. The value of the associated mass of water can vary within a wide range depending on the above conditions.

The associated mass of water, m_w, acting on a surface unit of hydraulic structure is determined (except for isolated structures such as water tanks, bridge abutments, piles and so on) by the following expression:

$$m_w = \frac{\gamma}{g} h \mu \psi \qquad (4)$$

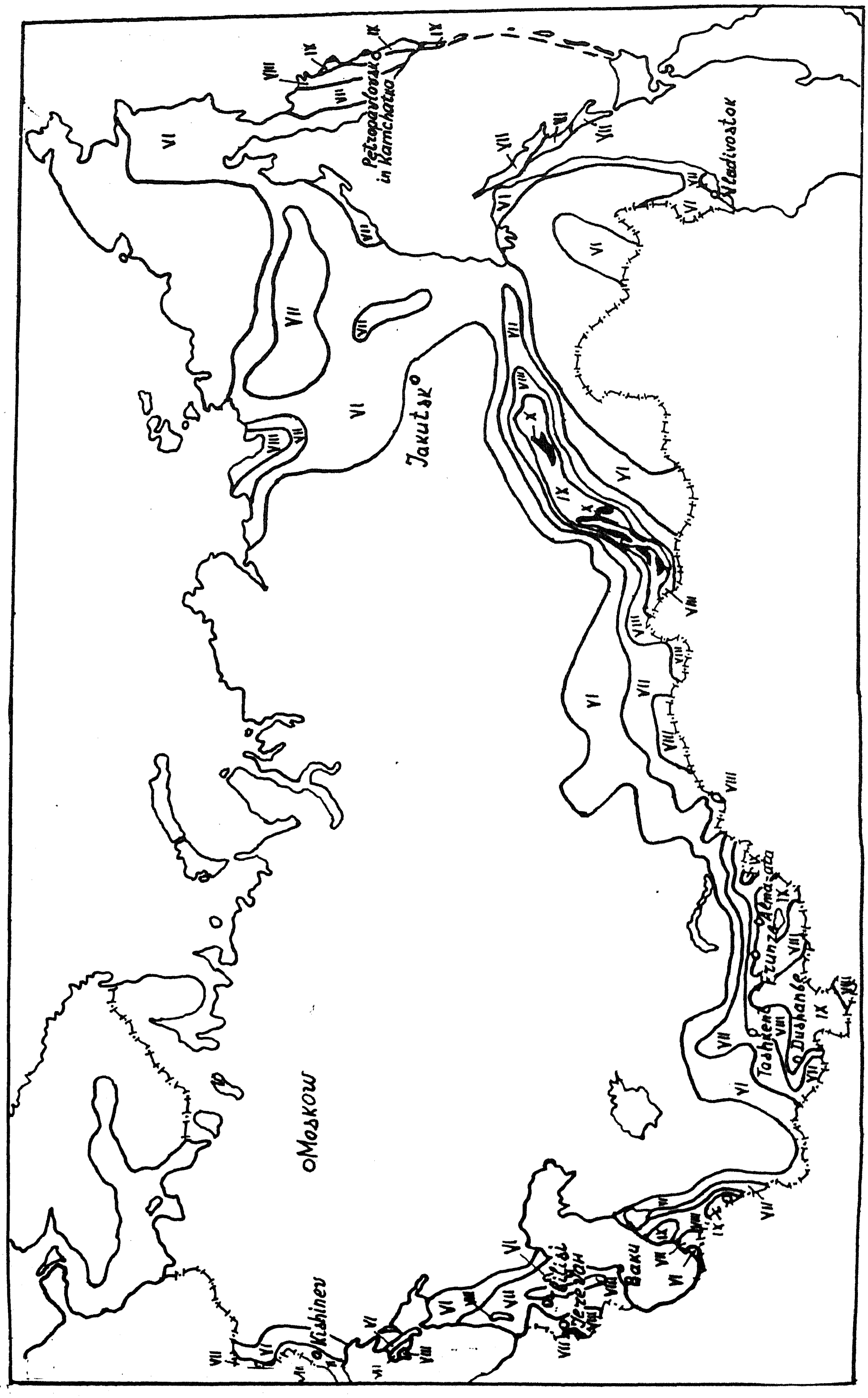
structures is not permitted on sites having active ruptures or in cases when the opposite walls of the canyon are formed of rocks with substantially different mechanical properties. Recommendations are given for the preparation of foundations in seismic zones.

Strength and stability calculations of hydraulic structures and their foundations are performed according to recommendations of the existing Civil Engineering Code of Practice (by admissible stresses or limiting states) with due consideration of the standardized values of material characteristics and safety factors for special load combinations. Therefore the new Standards give only some particular recommendations accounting for special features of the seismic action and the aseismic design. Particular instructions are presented in stability evaluation of canyon forming rock masses (collapse of which in the earthquake endangers structural safety), slope stability check-up of earth and rockfill structures and their possible flattening as a result of settling of cohesionless material as well as dynamic safety estimations of saturated cohesionless soils and materials. Some recommendations for earthquake stability design of hydraulic structures based on international experience in design, construction and operation of these structures in seismic zones are also included in the Standards /7, 8/.

In elaborating new Standards and Rules the "Hydroproject" Research Institute had conducted an extensive comparative research program on the seismic stability of dams of different types /9, 10/, in particular the 300 m high Nurek dam with boulder-gravel supporting fill and a loamy core and a 30 m high dam of homogeneous earthfill. Analysis of the test results shows that for the case of Nurek dam the total value of seismic load defined by the new standards /6/ is 35% lower than the same value defined by the old Standards /4/, the initial data being equivalent. At the same time for a 30 m high dam of homogeneous earthfill the total value of seismic load defined by the new Standards exceeds the same value defined by the old Standards by 25%. In the first case this leads to a decrease of the dam body volume by 8.25% while in the 2nd a 5.8% increase is obtained.

Equivalent comparative evaluations were performed for concrete gravity dams and arch dams. The results revealed that water influence evaluations based on the new Standards (represented as added masses) lead to the increase of the natural vibration period of concrete gravity and arch dams of medium and great height (up to 200 m) approximately by 25%, which results in a considerable decrease of the dynamic coefficient and inertia loads acting upon the structure. In conclusion it must be stated that the new Standards help to obtain a more valid estimation of hydraulic structure seismic stability which shows a better agreement with in situ and model test data.

In view of the long service life and high cost of important hydraulic structures comparison of the above methods should not be based solely on economic data. Measures must also be taken to ensure safety of the hydraulic structures designed and constructed in seismic zones. New Standards have already been utilized in the aseismic design of a number of major dams (Nurek, Inguri, Toktogul, Chirkey, Charvak hydropower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