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Systems For Monitoring And Predicting Seismic Safety Of Soil Hydraulic Structures (Dams)

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Annotation

This article investigates the problems of seismic safety of soil hydraulic structures, which can be destroyed in case of possible earthquakes. The issue of dam safety is of particular relevance, which at present in many states can lead to serious social, economic and environmental consequences.

Key words: Earthquake, dam, irrigation structure, seismicity, stability, reliability, safety, destruction, disaster, consequences, damage.

Introduction. In countries that are mostly agricultural, irrigation facilities, many energy systems and utility infrastructure are associated with the construction of various dams, dams and barriers. They are the most important objects of the economy of these countries, and especially countries where water resources are limited and rivers have variable currents, sometimes with very low water levels. Therefore, to meet the needs of the sectors of the economy of these countries, a corresponding accumulation of water is necessary. And in this regard, reservoirs play an important role for the production of electricity, for the uniform satisfaction of the water needs of agriculture, the supply of drinking water to the population, and, in general, for the sustainable functioning of other sectors of the economy [1]. On the other hand, they can be destroyed (for example, during earthquakes). Even their partial destruction or damage can lead to a breakthrough of the reservoir and almost instantaneous flooding of settlements, industrial facilities and agricultural land. Thus, enormous economic damage is inflicted with numerous human casualties, and environmental ecology is violated. At present, Uzbekistan has 273 hydraulic structures of various classes, including 55 large dams (as defined by the International Platinum Safety Committee), with a total water storage capacity of about 20 km^3.

Materials and methods. Based on the experience of studying the consequences of a number of earthquakes for the city of Tashkent, a methodology and concept for assessing seismic risk has been developed in order to draw up action plans to reduce it, which are quite acceptable for dams and other hydraulic structures, taking into account the adjustment of certain provisions that take into account their specifics.

Main body. The entire territory of the Republic of Uzbekistan is more or less prone to earthquakes, but not building dams with their hydropower units would mean limiting the development of many natural resources necessary for the development of the economy and the livelihoods of the population.

In this regard, dams began to be built in the Republic at the beginning of the last century, they were created even in territories where earthquakes were previously recorded. For example, in the area of the Charvak reservoir, a number of earthquakes were noted in the recent past: – Pskent 1973, with an intensity of 8 points, a magnitude of M=6 and a hypocenter depth of h=20 km; – Burchmulla with an intensity of 7 points, magnitude M=6 and focal depth h=15km; – Tavaksai 1977, with an intensity of 7 points, magnitude M=5, etc. [2].

In terms of technical and economic indicators, construction technology, here, earth dams are most widely used and of the 55 dams currently in operation:

–29–earthen homogeneous;
–17–earth (stone–earth) with a core;
–6 ground with a screen.

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The largest number of such dams are operated in the Nederlands (100%), in England (67%), the smallest – in Norway (1%) and Austria (12%).

But most of all earth dams are built in highly seismic regions of Japan, China and the USA. They are built from available and cheap local materials and on almost any basis. For example, in Japan over the past 70 years, 1852 dams have been built, of which 1227 are made of soil materials, including 43 rockfills. In the United States, 125 dams are built every year, and almost all of them are made of earth materials [3,4].

In Central Asia, the Charvak, Nurek, Rongun and other dams have been built from gravel–pebble and stone–earth materials.

But dams, like other hydraulic structures, can collapse when exposed to earthquakes. Statistics show that there are dozens of cases caused by damage to retaining structures due to seismic factors, and taking into account earthen dams, many hundreds of cases, including high dams of various designs [5].

Their failure is fraught with serious economic losses associated with a partial or complete cessation of the supply of consumers with water, electricity and heat.

About 15% of all dams built are damaged, failures and accidents in the world every year. About 70 –75% of these events are associated with earth dams. Widely known are major national–scale accidents of such dams with human casualties, with great social and environmental damage6: Machhu–11 (India); Buffalo Creek, Canyon Lake and Teton (USA); Tous (Spain); Touhou (China); Orosi (Brazil); Haiokori (South Korea) and others.

Therefore, the issue of dam safety is of particular relevance, since at present in many states there are a significant number of dams, damage or destruction of which can lead to serious social, economic and environmental consequences. For example, the destruction of the dams of Lake Sarez threatens to flood the cities of Uzbekistan, Tajikistan, Afghanistan and, to a lesser extent, Turkmenistan [5], the Charvak reservoir poses a potential flood hazard for the city of Tashkent and its suburbs.

In the republics, where, in addition to reservoirs, there are 23 river water intake facilities and 180 village storage facilities. Of particular danger are areas of landslide overlaps that contribute to the emergence of lakes. Now in the mountainous folded regions of Uzbekistan and adjacent territories of Kyrgyzstan and Turkmenistan, there are about 43 mountain dammed lakes. Of these, 11 are located in Uzbekistan, 119 in Kyrgyzstan, 12 in Tajikistan [6].

Many water management facilities were built a long time ago. Thus, the Asaka hydroelectric complex and the Salar hydroelectric power station were built in 1926. The Ravatkhoja hydroelectric complex was built in 1929. The Great Fergana Canal was built in 1939, and the last reconstruction of the Dargom Canal in 1930, the Kattakurgan Reservoir was built in 1941. By 2000, capital repairs were carried out only on 6 reservoirs. The rest of the facilities need repair or replacement of metal structure equipment, strengthening of the tailwaters, etc. Monitoring of the village storages is carried out at an insufficient level, so it is difficult to judge their technical condition [2].

Over the past 100 years, about 400 soil dams, dams and embankments have experienced the impact of earthquakes of varying intensity from 4–6 points and higher [7]. At the same time, the number of damages and accidents of these structures caused by earthquakes in different countries ranged from 1 to 6% compared to the number of such cases from other causes. According to the static data of 1966, for example, out of 1226 dams in Japan, 90% of which had a height of more than 15 m, they received deformations and damages, in 6% of cases their causes were associated with earthquakes. The table shows data on the behavior of some hydraulic structures made of soil materials during some earthquakes that occurred with an intensity of more than 6 points.

Conclusions. An analysis of the consequences of the impact of earthquakes on earth dams once again confirms that the issue of their safety is of particular importance and relevance because in many states there are a significant number of dams, damage or destruction of which can lead to serious social, economic and environmental consequences. Hence the need arises to ensure the

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safety of each dam, for this it is necessary to take all measures to ensure that this structure does not pose a threat to people's lives, their health, property, as well as to the environment.

To increase the stability of hydraulic structures and their safe operation, it is necessary, in our opinion, within the framework of the requirements of the Law of the Republic of Uzbekistan dated 20.08.1999 Number of 826–i “On the safety of hydraulic structures” and the Resolution of the Cabinet of Ministers. Republic of Uzbekistan. dated 20.08.1999 Number of 827–i., periodic control inspection and periodic assessment and forecast of strength, reliability and monitoring of hydraulic structures with the involvement of relevant specialists from scientific organizations, providing each structure with the organization of regular repair and restoration and strengthening work, as is done at residential and industrial construction sites.

This applies to all water management facilities of the Republic, many of which have already worked out or are close to working out 40–50 years of operation, their safety margins are being exhausted and in need of major repairs. When performing these tasks, it is necessary to conduct research work to assess and reduce the seismic risk of dams and other critical hydraulic structures, using modern methodologies based on both domestic and international experience.

Monitoring and forecasting of natural and man–made hazards.

Monitoring and forecasting activities are implemented within the framework of the emergency monitoring and forecasting system, which is designed to [3]:

– organizing and carrying out work on early identification of sources of natural and man–made emergency situations;

– determining the possible scale of emergency situations and the nature of their development;

– identifying the causes of emergency situations;

– development of recommendations for the prevention, prevention and localization of emergency situations and mitigation of their consequences (Fig. 1.).

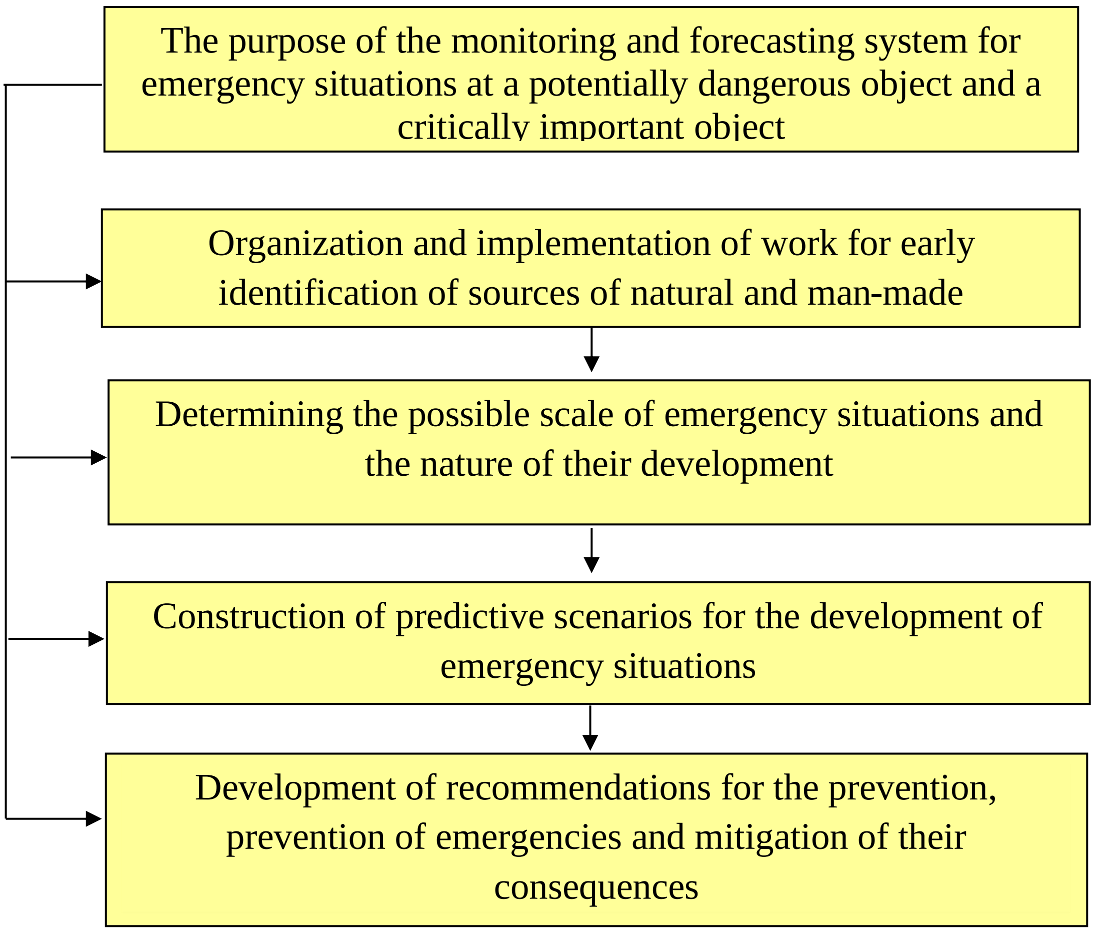

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Fig. 1. Purpose of the monitoring and forecasting system for natural and man–made emergencies at the facility

The activities of any monitoring and forecasting system include work aimed at:
– determination of the object of observation;
– inspection of the observation object using technical means;
– drawing up an information model of the observation object;
– planning and conducting observations using established technologies;
– assessing the condition of the object;
– forecasting changes in the state of the observed object;
– presentation of information in the required form and delivery to consumers;
– maintaining archives and routine maintenance with means of observation and information processing.

The main tasks that are solved by the system for monitoring external hazards and diagnosing the condition of the facility and process equipment are [4, 5, 6, 7, 8, 2]:
– monitoring of hazardous natural processes in litho–, hydro–, atmospheres on the territory of the facility and adjacent areas;
– ensuring the prompt collection of the necessary information from the facility in order to formulate a strategy to prevent an accident from occurring and to localize an accident if it occurs;
– ensuring a stable condition of the object;
– notifying personnel in the event of complex non–standard situations, etc.

Thus, the purpose of monitoring is to observe, control and predict dangerous processes and phenomena of nature, the technosphere, external destabilizing factors that are sources of emergencies, as well as to assess the dynamics of emergency development, determine their scale in order to solve the problems of preventing and organizing disaster relief.

The main goal of emergency monitoring is to identify the state and trends in changes in natural, man–made, military, biological and social elements of the environment that can lead to an emergency.

In the practice of technical monitoring of the condition of an object and technological equipment, there are parameters of the reliability and survivability of the object, which are measured by vibroacoustic, flaw detection, introscope, structural measuring procedures [9, 10]. Technical diagnostics includes checking the serviceability of equipment and its performance; searching for defects in objects during production and operation.

To monitor and diagnose the condition of an object and technological equipment, a wide range of testing equipment is used, instruments for determining hardness, elastic constants of materials, the effects of climatic factors, tensile, compression, bending, torsion tests, etc. [9, 10]. Depending on the amount of information, general indicators or specific parameters are considered. Generalized indicators characterize the state of a system module or subsystem as a whole, and private indicators reflect the state of a specific node or block of the system [9, 10].

When monitoring the technical condition of an object (PDO or CIO), the selection of diagnostic monitoring parameters that will fully characterize the condition of the object is a difficult task. For this purpose, a special analysis is carried out to determine how adequately the selected parameters informatively and unambiguously reflect the state of technological equipment, building structures, and engineering [9, 10].

Based on monitoring of technological processes and technological equipment, engineering systems and building structures, the technical condition of the facility as a whole is assessed. The assessment consists of comparing the current values of the measured diagnostic parameters with their standard values: the initial standard, that is parameters of new serviceable objects; acceptable standard, that is basic diagnostic standard; maximum standard (state of an object in which its further operation is impractical or impossible) [10, 11].

For CIO and PDO, the tasks of technical monitoring are related to the scenario presentation of the forecast of the consequences of accidents and emergencies. Modeling options for forecasting the development of emergency situations is based on information about the stress–strain state, the main factors damaging equipment and the structure of the facility, the kinetics of damage and the equations that determine these processes [9, 10].

Assessment of the technical condition of an object and technological equipment with the subsequent determination of the residual life of load–bearing elements of equipment of complex technical subsystems is carried out by various combined calculation methods and is necessary to determine the characteristics of the strength, reliability and durability of the object as a whole. Details about calculation methods and procedures for determining the characteristics of strength, reliability of an object and technological equipment can be found in [9, 10, 11, 14].

We provide general information on monitoring systems for the most dangerous production facilities.

Monitoring the safety of hydraulic structures (HS) is carried out in accordance with the Instructions [15], where HS monitoring is defined as a set of permanent continuous observations of the safety state of HS and the nature of their impacts on the environment.

Instruction [15] is mandatory for all participants in the processes of design, construction, operation of hydraulic structures and for all forms of ownership of hydraulic structures supervised by the State Technical Supervision Authority of the Republic of Uzbekistan.

Monitoring is carried out with the aim of ensuring constant control over the safety status of hydraulic structures and their impact on the environment, preventing the occurrence of emergency situations and creating conditions for safe operation.

The objects of monitoring are [15, 2]:

– industrial hydraulic structures (industrial waste storage facilities; tailings storage facilities, sludge storage facilities, hydraulic dumps, settling ponds, drainage and sludge water storage facilities) including:
– alluvial and embankment fencing and retaining dams and dams;
– soils of the hydraulic structure foundation in the influence zone;
– hydraulic transport and recycling water supply systems, including settling ponds;
– main technological equipment;
– environmental protection structures designed to prevent the harmful effects of the storage tank;
– design and operational documentation of the above mentioned objects;
– the state of the training process and the procedure for preparing personnel training.

The main technological processes to be monitored at the HS [15, 2, 16]:

– technology of storage, sludge washing and industrial waste storage;
– technology of clarification and circulation of process water;
– hydraulic transport technology;
– technology for reclamation and decommissioning of waste storage facilities;
– technology for re–development and extraction of sludge from a mothballed reservoir;
– drainage of industrial waste storage tanks;
–technology of industrial processing of toxic waste.

The main functions of HS monitoring are presented in Fig. 2. [15, 9, 2].

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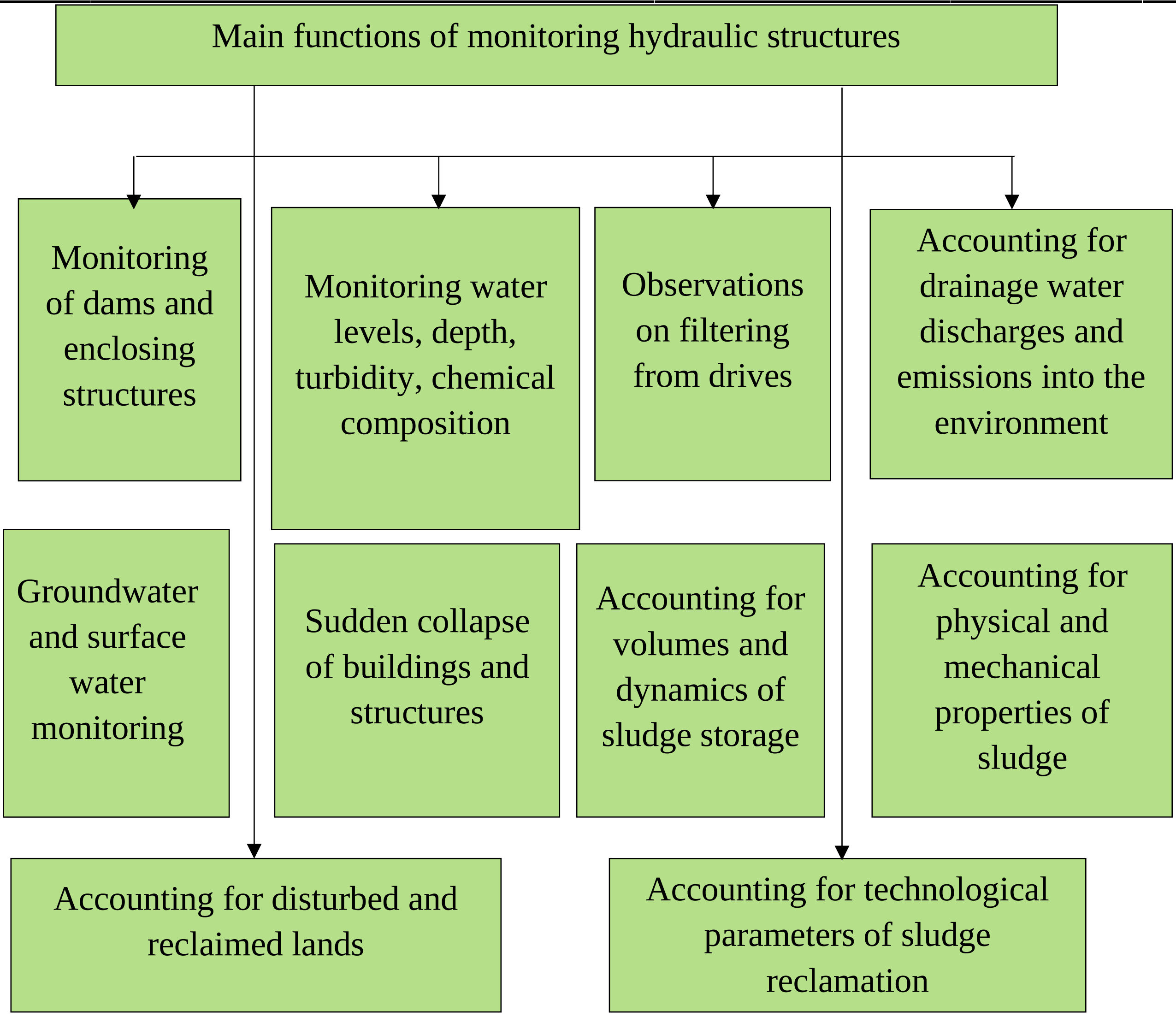

Fig.2 Main functions of the hydraulic systems monitoring system

A special place in on–site hydraulic structures monitoring systems is occupied by monitoring the condition of water–pressure hydraulic structures of hydroelectric power plants (dams) [15, 2].

Forecasting emergencies caused by hydrodynamic accidents on hydraulic structures is an integral part of monitoring hydraulic structures and includes:

– forecast of the degree of destruction of hydraulic structures;
– forecast of parameters of the breakthrough wave formed during the destruction of hydraulic structures;
– forecast of the post–emergency state of the riverbed and floodplain in the flood zone;
– collection, storage and processing of source data;
– forecasting the consequences of accidents for the population, facilities and surrounding areas.

This applies to all water management facilities of the Republic, many of which have already reached or are close to reaching the end of their 40–50 year service life, their safety margins are being exhausted and are in need of major repairs. When performing these tasks, it is necessary to carry out scientific research work to assess and reduce the seismic risk of dams and other particularly important hydraulic structures, using modern methodologies based on both domestic and world experience.

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Table №1.
Information on damage and destruction of some underground hydraulic structures as a result of past earthquakes

Plotina account	Dam (country)	Year of construction	Dimensions of the construction site dam, m			Slope		settings against filtration device	Geological basic conditions basics	geological conditions of the foundation dam before the earthquake year	earthquake data	signs of deformation and damage
			height	ridge length	width	upper	lower					
1	2	3	4	5	6	7	8	9	10	11	12	13
1	San Andreas (USA)	1870	29.0	272	7.5	3.5	3.0	compacted clay	deluvium 12.2, underlain by a rock	5	1875 year	destroyed
										28	1898 year	Destroyed on April 18, 1906
										36	18.04.1906y. San Francisco, M=8,3, acceleration– 0,25g, the gap went through the dam	Ridge shift by 2.0 m; longitudinal cracks along the ridge 7.5 cm wide, long 45 m, there were also transverse cracks (Fig. 3) [7].
2	San Fernando lower (USA)	1912–1930	43,3	–	–	–	–	homogeneous of loos soils	A layer of alluvial deposits underlain by a rock тош	58 after strengthening –47	7.11.1971; Los Angeles (Calif.), USA); M=6,6 point, R= 14 km, A=0,4–0,5g,	Landslide of the bank and the upper prism 305 m long due to soil lquefaction (Fig. 4) [7]

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Fig.3. A shift in the San Andreas earth dam from the impact of a magnitude 10 earthquake in 1906. [9].

Fig. 4. View of the lower San Fernando dam after the earthquake [7].

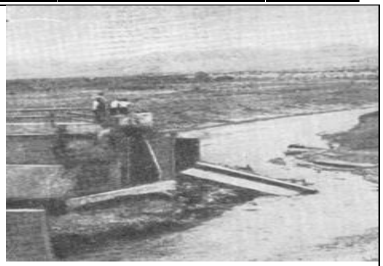

Fig.5. Collapsed earthen dam at Rogers Dam [10]

3	Bhuj (India)	As a result of the earthquake on January 26, 2001.: Bhuj, with M=7.9 and J=8 points, 245 small earthen dams and dams received damage of varying severity. 80 thousand people died (Fig. 8) [8].										
4	Rogers (USA)	As a result of the earthquake on August 23, 1954 in the city of Fallon with M=6.6; J=7 b., R=57km, a=0.07g Rogers Dam earth dam was completely destroyed [9] (Fig.5) [10].										
5	Sichuan (China)	May 12, 2008 an earthquake occurred in Sichuan with M=7.9–8.0 and J=11 points. As a result of tremors of varying degrees, 1583 dams of various types were damaged, including several large ones. 69 thousand people died, several million were left homeless (Fig. 9) [8].										
6	Tarbela Pakistan	1968–1977	147.9	2700	–	1:2.65	1 turn 1:1.8 at full height 1:1.70	Inclined Gravel Core	Alluvial deposits 60–120 m underlain by rock	–	06/31/1974; Two seismic shocks cM=6.5; points, R=0 km	Destruction of a tunnel 60 m long, removal of upstream prism material, rock erosion in the downstream

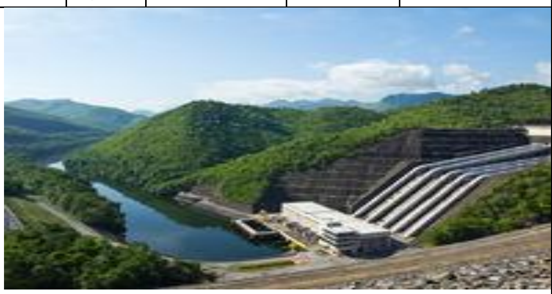

Fig.6. The Tarbela Dam is an operating hydroelectric power station in Pakistan on the Indus River, one of the largest power plants in the country (capacity–3478 MW). Located 50 km from Islamabad. The construction of the HPP began in 1968 and was completed in 1977. Since the main source of the Indus is the melting of the glacial waters of the Himalayas, the river carries a huge amount of sediment. The annual amount of sediments is about 430 million tons. This means that over time, the reservoir will overflow. The useful life of this dam is estimated to be somewhere around fifty years, after the completion of the dam in 1977, the reservoir would have been filled by 2030. However, sedimentation is now much lower than previously

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predicted. Currently, it is estimated that the life of the dam will be 85 years, until 2060 [11].												
 **Fig. 7. Damage to the dam of the Chiryurt hydroelectric power station during the Dagestan earthquake on 05/14/1976 [7]**					 **Fig.8. Longitudinal cracks on the upstream face of the Feitigadh Dam (India), caused by the Bhuj earthquake on January 26, 2001[8].**				 **Fig. 9. Fragments of damage to the Zipingpu dam during an earthquake in Sichuan[8]**			
8	**Chiryurt skye (Russia**	**1964**	**37,5**	**540**	**9,5**	**2,5–3,5**	**2,0–2,5**	**Central loamy core**	**Alternating layers of dense clays sandstone**	**6**	**[illegible] estan, Russia) ; M=6.6; J=8 points, R=30km,**	**displacements up to 20 cm along the top wedge cracks. Transverse cracks in the [illegible]**
7	**Lake Yashinkul (Kyrgyzstan)**	**As a result of the Tashkent earthquake on April 26, 1966 with M = 5.3, J = 8.2, the crest of the dam of Yashinkul Lake sank and in June 1966, due to prolonged rains, the lake overflowed and on June 18 the natural dam broke through. At 1.5 from the dam, due to the erosion of about 3 million m3 of soil, a 12 m high rock mudflow was formed, which collapsed into the valley of the Tegirmoch River [1].**										

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