STRUCTURAL CONTROL OF A HIGH ARCH DAM

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SUMMARY

Feasibility study of vibration control systems applied to massive structure, a 292m high arch dam is carried out.

Seismic analyses of the arch dam including nonliear behavior of joint movements demonstrate, that installation of viscoelastic dampers in the contraction joints can reduce the maximum tensile stresses at major part of the dam to a great extent.

Effectiveness of mounting mild steel dampers in the contraction joints is also studied.

Rational way of layout of the control devices in the dam is examined.

INTRODUCTION

The development of structural control has been rapid over the past decade. A great many structural protective systems have found their use in the construction of buildings, towers and bridges. However, the structural control of massive structures, such as dams, has been little tackled in the literature.

Dams impounding large amount of water in the resesvoir , their failure may cause serious consequences. The safety of dams against earthquake shocks is of great importence. Adding structural control devecies to dams to promote their energy dissipation capacity has the potential for significantly reducing seismic risks and enhancing safety, reliability and economy. The purpose of this paper is to carray out feasibility study to assess whether the dynamic perfomance of a high arch dam can be singificently improved by the installation of energy disssipation devices.

A large arch dam, 292 meter in height, is planned to be built in the southwest part of China in seismic active area. The dam is a parabolic double curvature structure, the thickness of the crown section varies from12.00m at the crest to 73m at the base. Fig.1 shows the plan and elevation of the dam. The basic earthquake intersity of the dam site is as high as VIII of Chinese scale (nearly equivalent to MM scale). According to the specification for seismic design of hydraulic structures of China, The dam is regarded as frist grade important structure, the design acceleration of the dam is 0.308g, which corresponds to probability of exceedance 2% in 100 years.

Arch dam are constructed as cantilever monoliths separated by contraction joints . The whole crest length of the dam 935m is devided by nearly uniformly spaced 48 contration joints. As the joints cannot transfer substantial tensile stresses, it is expected that two adjacent sides of the joints may undergo relative movements during strong earthquakes. It results in redistrubution of the dynamic stresses over the dam body, a signigicant amount of tensile stressess in the arch direction will be released and stressess in the cantilever direction may be developed. Because earthquake load is dominant for the dam, engineering measures have to be taken to reduce the seismic response. Strengthening the dam by steel reinforcement, stretching across the contraction joints has been considered, total required reinforcement is estimated as 87-140 thousand tons. Implementation of energy dissipation system instead of reinforcement provides a more attractive alternative to solve the problem.

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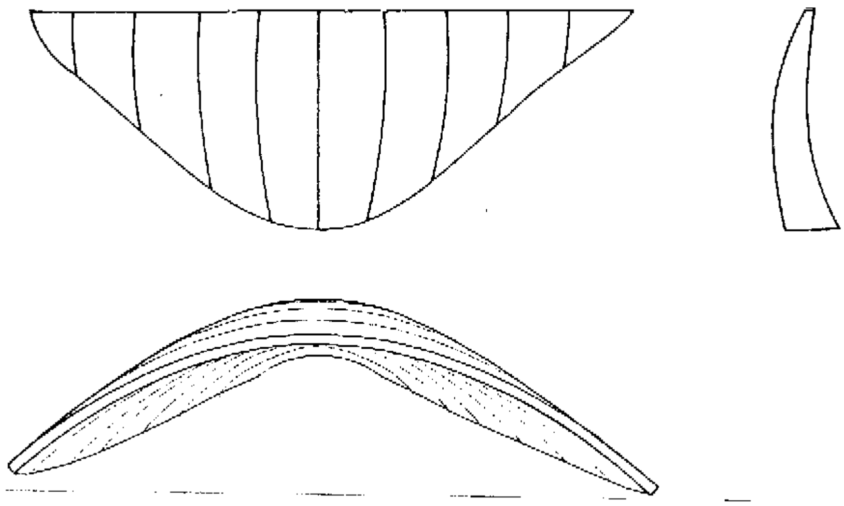


Fig.1 the Arch Dam

GENERAL LAYOUT OF ENERGY DISSIPATION DEVICES

Nonlinear seismic analyses of the arch dam taking into consideration opening of the contraction joints and transfering of loads from arch action to cantilevers action during strong earthquakes have been carried out. The focus of this paper is on the possibility of implementing passive energy dissipation system to arch dam , rather simple model was used. The foundation rock in represented as a massless finite element model and uniform free-field motion is specified at the canyon interface. Dam-water interation effects are represended by an adjusted added mass matrix for the incompressible water in the reservoir. Although introducing more sophisficated model, including dam-foundation interaction with semi-infimite half space and spatial variation of the free-field motion along the canyon is not difficult[3].

A hybrid finite element computer program is developed to solve the dynamic contact problem of joint movements[4]. Normal and tangentical displacements between the two surfaces of the joints are determined by successively searching approach, satisfaction of the contact condition at each time step is checked.

The effects of energy dissipation devices are simulated by springs and dashpots. The energy dissipating devices are assumed to be installed in three contraction joints of the dam (at central and quarter points of the dam crest). Other joints are locked by certain lock devices.

Layout of the energy dissipation devices along the contraction joints in a more rational way is examined. Comparison of installing the control devices in the arch driection (normal direction of the joint) and that in the radial direction (tangential dicetion of the joint) reveals that installing such devices in the arch direction is much better than that in the radial direction. The radial displacements, radial accelarations as well as arch and cantilever stressess of the dam can be adjusted by the control devices set up in the arch direction, while dynamic response of the dam is little influenced by the control devices put in the radial direction.

Control divices are assumed to be installed in different levels of the contraction joints along the dam height, the space between each of the two levels is 30 to 40 meters. Effectiveness of 3 to 6 levels from the top of the dam are compared. This study has demonstrated that control devices mounted at 3 top levels of the dam are sufficient. The seismic response of the dam is little affected by adding the control devices to 4 or more levels.

Results of nonlinear seismic analysic also show that control devices arranged in 3 lines (upstream side, downstream side and central line) along the width of the contraction joints are adequate. One or two lines are less effective

SEISMIC RESPONSE OF HIGH ARCH DAM WITH VISCOELASTIC DAMPERS

During strong earthquakes, the arch dam vibrates mainly in its fundamental periods. The relative motion between the two sides of the contraction joints is rather small. So it is desired that the control devices dissipate energy at small movement.

Implementing viscoelastic dampers as control devices is studied. Viscoelastic (VE) materials are typically copolymers or glassy substances, which have the dynamic behaviour of both rubber and clay and which dissipate energy when subjected to shear deformation. Typical damper configuration and their installation in contraction joints are given in Fig.2. Under sinusoidal load with frequency ω the stress-strain relationship is expressed in the form [1]

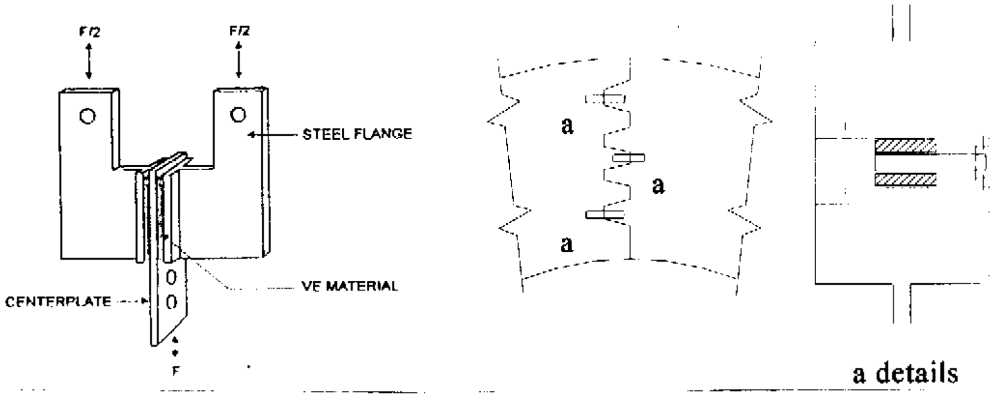


Fig.2 Viscoelastic Dampers and their Installation in Contraction Joints

$$\tau(t) = G'(\omega)\gamma(t) + \frac{G''(\omega)}{\omega}\dot{\gamma}(t) \tag{1}$$

where τ and γ are, respectively, shear stress and shear strain; $G'(\omega)$ and $G''(\omega)$ are defined as the shear storage modulus and shear loss modulus respectively. $G'(\omega)$ and $G''(\omega)$ are generally functions of excitation frequency (ω), ambient temperature (T), shear strain (γ), and material temperature (θ). Values of $G'(\omega)$ and $G''(\omega)$ could be estimated by the curve depicted in Fig. 3[1].

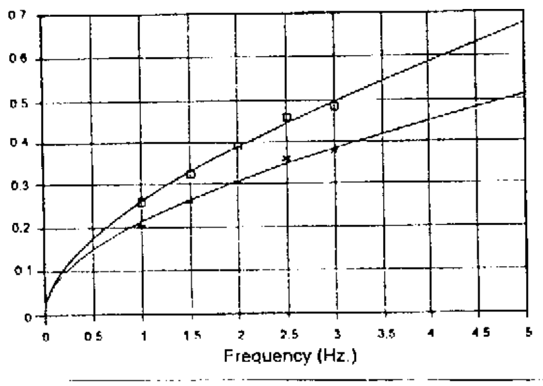


Fig. 3 Storage and Loss Moduli of VE Material

In the analyses of structural response under harmonic motion, the stress in a VE material at a given ambient temperature and under moderate strain could be expressed as linearly related to the strain and strain rate, or the corresponding force-displacement relationship could be written as [1]

$$F(t) = k(\omega)x(t) + c(\omega)\dot{x}(t) \tag{2}$$

where $F(t)$ and $x(t)$ represent force and displacement, respectively; while $k(\omega)$ and $c(\omega)$ are expressed in terms of shear area A and total thickness h of VE material.

$$k(\omega) = \frac{AG'(\omega)}{h}, \; c(\omega) = \frac{AG''(\omega)}{\omega h} \tag{3}$$

Dynamic response of the arch dam subjected to design earthquake in case of full reservoir and in case of partially full reservoir (the water level in the reservoir is 64m below the crest of the dam, which corresponds to usual low water in the reservoir) are calculated. The tensile stresses (minimum principle stresses) developed at the upper part of the dam in the later case are dominant.

Numerical time history analyses are performed. Envelop of the stress distribution of the dam when it act as a monolithic structure is plotted in Fig.4 and Fig.5, the scale given in the figures corresponds to 10MPa(the same hereinafter) , while stress distribution of the dam with VE dampers is plotted in Fig.6 and Fig.7.

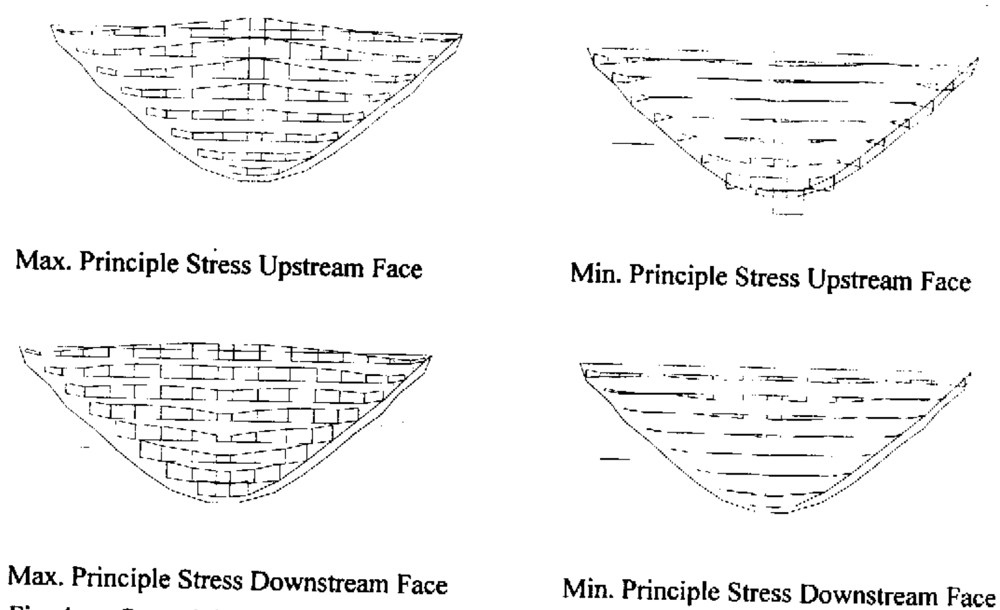


Fig. 4 Stress Distribution of the Dam(Monolithic Structure) in case of Full Reservoir

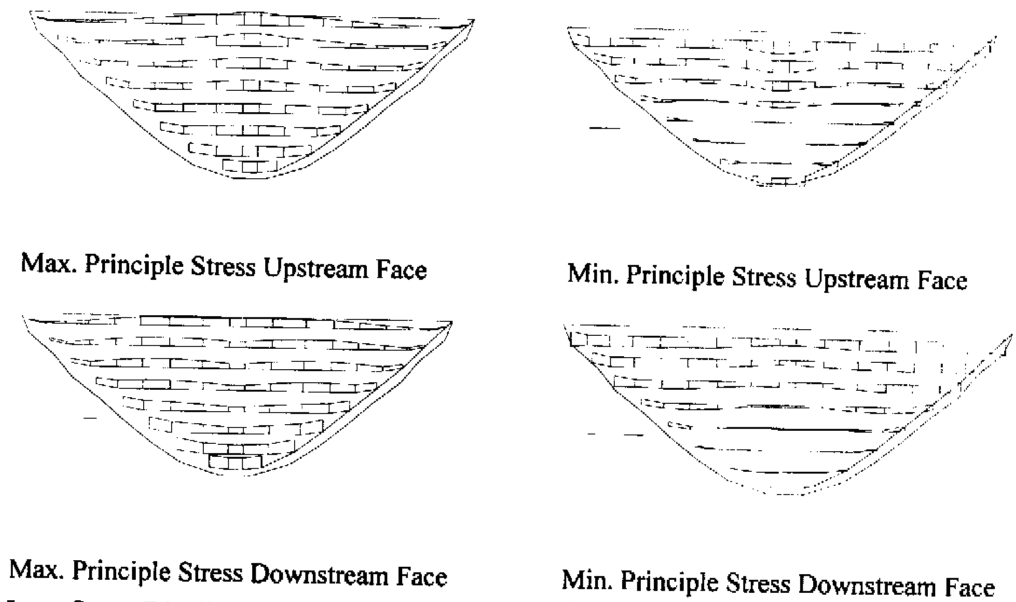


Fig.5 Stress Distribution of the Dam(Monolithic Structure) in case of Partially Full Reservoir

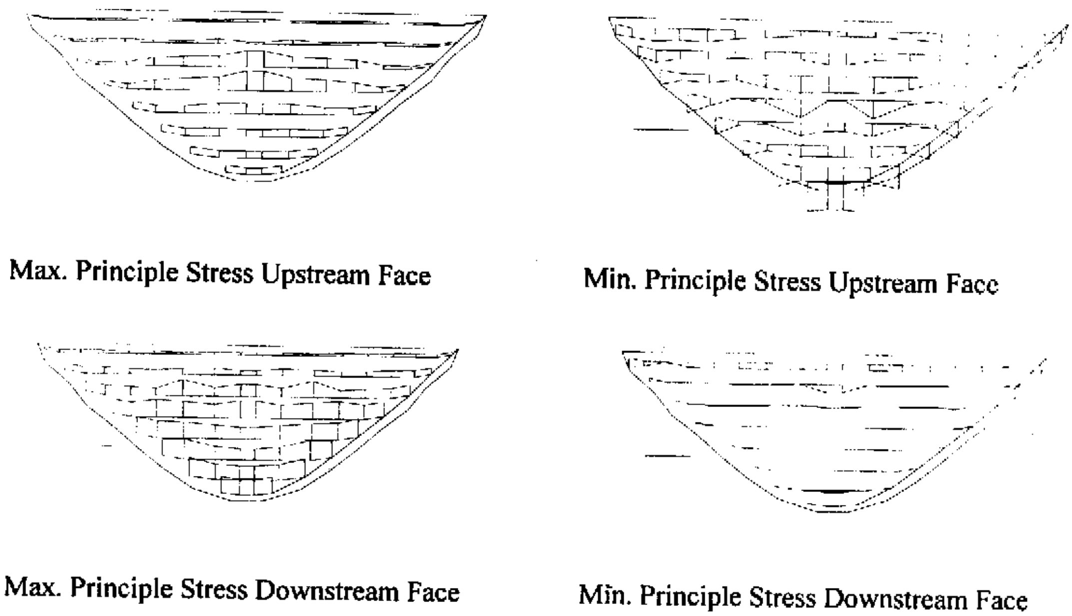


Fig.6 Stress Distribution of the Dam with VE Dampers in case of Full Reservoir

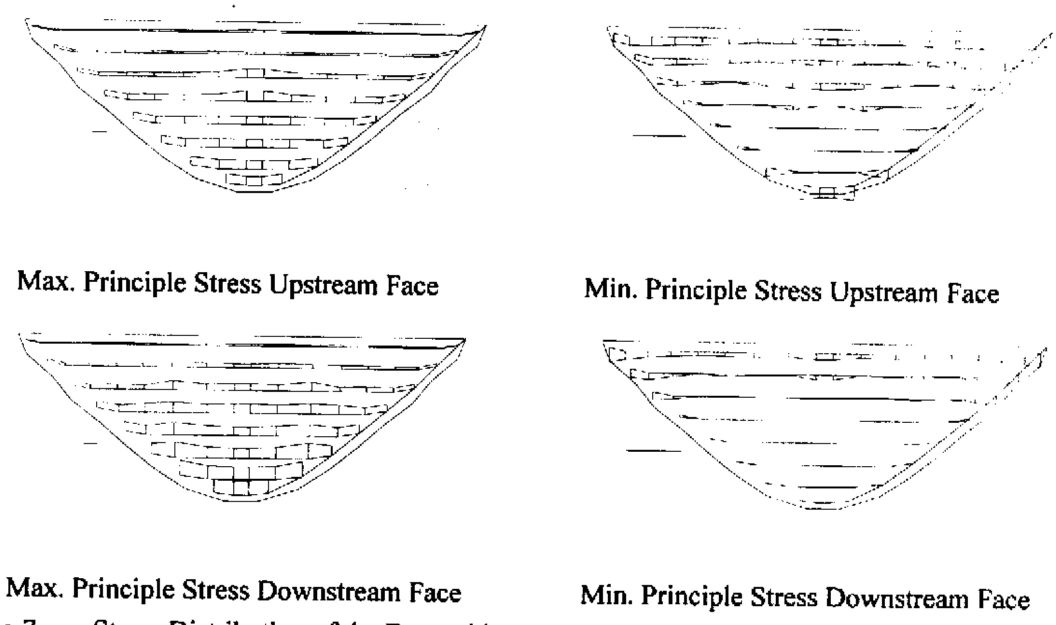


Fig.7 Stress Distribution of the Dam with VE Dampers in case of Partially Full Reservoir

It can be seen from these figures, that by installing VE dampers the maximum tensile stresses at major part of the dam could be reduced to a great extent. For example, stresses at central part decrease from 2.44 MPa (upstream face) and 1.16 MPa (downstream face) to 1.02Mpa(upstream face) and 1.09 MPa (downstream face). While stresses near abutments decrease from 1.94 MPa (upstream face) and 2.67 MPa (downstream face) to 1.42 MPa(upstream face) and 2.46 MPa (downstream face). The effectiveness of VE Dampers is obvious.

SEISMIC RESPONSE OF HIGH ARCH DAM WITH METALLIC DAMPERS

Dynamic response of arch dam with X-shaped mild steel dampers (Fig.8) is also studied. Such devices are displacement dependent.

Fig.9 and Fig. 10 show the stress distribution of the dam with mild steel dampers. Maximum tensile stresses at major part of the dam are also reduced by 10-20%, however, it is less effective than VE dampers.

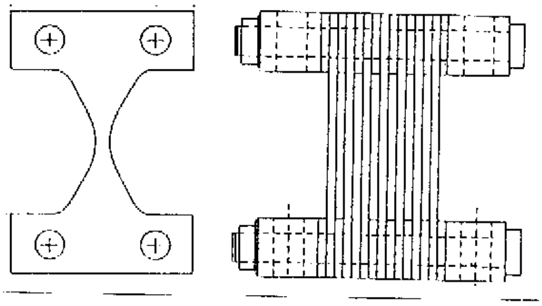
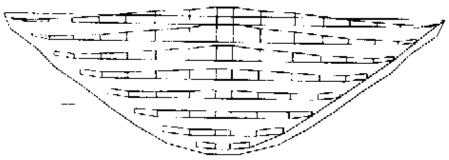
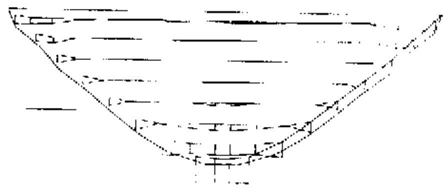


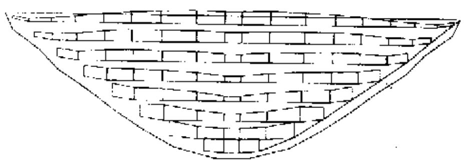
Fig. 8 X-shaped mild steel plate damper



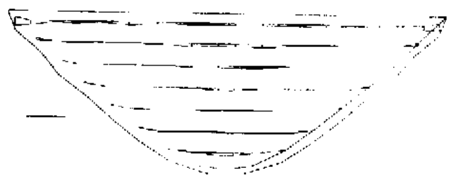
Max. Principle Stress Upstream Face



Min. Principle Stress Upstream Face

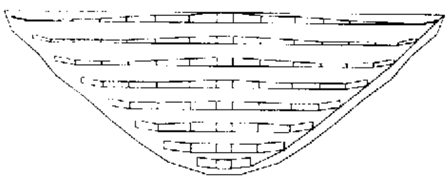


Max. Principle Stress Downstream Face



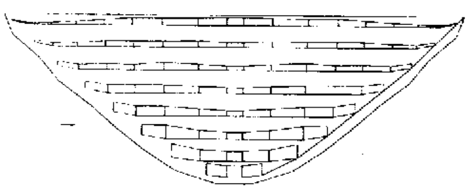
Min. Principle Stress Downstream Face

Fig.9 Stress Distribution of the Dam with mild steel in case of Full Reservoir

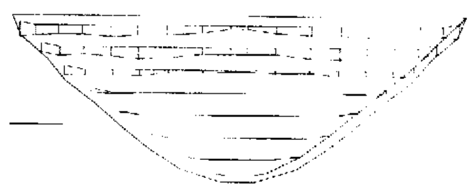


Max. Principle Stress Upstream Face

Min. Principle Stress Upstream Face



Max. Principle Stress Downstream Face



Min. Principle Stress Downstream Face

Fig.10 Stress Distribution of the Dam with mild steel in case of Partially Full Reservoir

CONCLUSION

Feasibility study of implementing vibration control systems to high arch dam, a kind of massive structures, has been carried out.

Dynamic analyses taking into account the nonlinear behaviour of joint movements reveal that installation of energy dissipating devices in the contraction joints is effective to reduce the seismic response of the dam.

With regard to the efficiency of energy dissipation, frequency dependent viscoelastic dampers are better than displacement dependent mild steel dampers. Installation of control devices in the arch direction of the joints is more rational than installation of such devices in the radial direction.

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