EXPERIMENTAL AND NUMERICAL STUDY ON ROCK FALL IMPACT ON A FLEXIBLE ROCK-SHED STRUCTURE

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Summary A new concept of flexible rock-shed protection structure is proposed in this paper. The flexible rock-shed protection structure is made of ring nets held up by specially designed steel vaulted structures. An 1:1 prototype was manufactured and tested for functional evaluation with impact experiments. Finite element analysis was carried out by using commercial CAE software package LS-DYNA to simulate the impact tests for the purpose of structural analysis and optimum design. The results obtained from the numerical simulation are compared to experimental data to assess the accuracy in predicting the dynamic behaviour of the structure.

INTRODUCTION

In mountain areas, highways or railways are often laid out on steep slopes and must be protected from falling rocks at the most hazardous spots by constructing structures that cover them. Such type of conventional structures are called rocks-sheds. As shown in Fig.1, these structures are generally composed of reinforced concrete sub-structural elements (walls, column and foundations) and a roof slab [1]. The main disadvantage of this solution is the need for massive foundation due to the deadweight of the structure. In addition, constructing such foundations along steep slopes with frequently poor quality bedrock is usually very difficult and expensive. In order to overcome such construction difficulty and to reduce costs, a new type of flexible rock-shed structure is proposed (Fig.2). The system is designed to stand for an impact energy of about 250kJ considering the weight of a general-size rock block. The ring nets (Fig. 3) is subjected to direct impact and the kinetic energy from a falling rock block is dissipated directly by the plastic deformation of the ring nets and by the elastic deformation of the steel vaulted structure (Fig.4) in case of a central impact. For impacts on the edges, the system can absorb energy of rock falls without severe structural damage.

Fig.1 Conventional solution including a roof slab

Fig.2 Flexible rock-shed including ring nets and steel vaulted structure

Fig.3 Ring nets

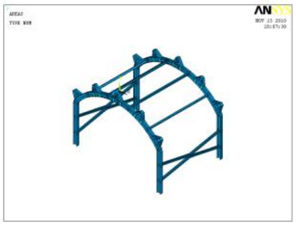

Fig.4 Steel vaulted structure

EXPERIMENTS

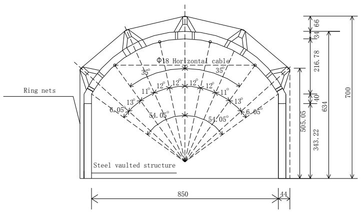

Fig.5 Transversal section of the experimental system

Fig.6 Concrete block for impact test

An 1:1 scale prototype was created and assembled and installed in field. It consists of an 8.5m wide and 7.0m height steel vaulted structure with ring nets hanged over the structure (Fig.5). In order to simulate rock falling impact, a cubic reinforced concrete block with a mass of approximately 800kg was lifted to a height about 39m and then dropped from a crane to hit the model with an impact speed of about 25m/s and impact energy of about 250kJ (Fig. 6). The steel vaulted structure was equipped with a set of sensors connected to a data acquisition station and a high-speed camera (300 frames per second) was used to record the impact of the block onto the system.

NUMERICAL SIMULATION

Ring behaviour in Tensile Loading Test

The ring nets are connected by wire rings with a diameter of ϕ300 mm made of high strength wire ϕ3 mm turned 7 windings, which are held together by small clamps. The mechanical analysis of a complex structure, such as the ring nets, imposts first on the non-linear behaviour and the energy capacity of a single wire ring. Quasi-static tensile tests were performed (Fig.7). The force-displacement curves are shown in Fig.8.

For the single wire ring turned by 7 windings, the load can be averagely applied to the wire on each circle. The force and displacement relationship of the ring with radius R and cross-section radius r ($r << R$) ($P-\delta$ curve) can be described by the approximate balance equation [2]. In the balance equation, P is the tensile force, θ is the angle, δ is the displacement, M_p is the limited plastic moment and σ is the cross-section yield stress, r_1 is the equivalent radius of wire rings.

Fig.7 Tensile test on a single wire ring

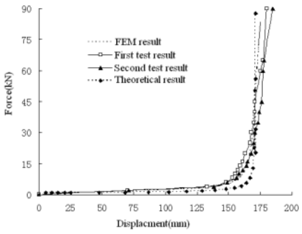

Fig.8 The force—displacement curves for single ring

$$\frac{P}{2}R(1-\sin\theta)=2M_p \tag{1}$$

$$\delta=2R(\cos\theta+\theta-1) \tag{2}$$

$$M_p=\frac{4}{3}\sigma r^3 \tag{3}$$

Substituting Eq. (3) into (1) yields

$$\frac{P}{r^3}=\frac{16\sigma}{3R(1-\sin\theta)} \tag{4}$$

Assuming that the wire rings turned n windings, if a single wire ring bears the load P, the wire rings turned n windings can bear the load nP. Consequently, Eq. (4) can be rewritten as

$$\frac{nP}{r_1^3}=\frac{16\sigma}{3R(1-\sin\theta)} \tag{5}$$

The force-displacement curve of a single ordinary ring is the same with the wire rings. Hence from Eqs. (4) and (5) one has

$$\frac{P}{r^3}=\frac{nP}{r_1^3} \tag{6}$$

So the equivalent radius of wire rings can be written as

$$r_1=n^{\frac{1}{3}}\cdot r \tag{7}$$

The force-displacement curves of from numerical simulation and the preceding theory coincide pretty well with the test data, as shown in Fig. 8. The ring nets model can be simplified by using the equivalent radius of wire rings. The flexible rock shed is a very complicated system. Many research efforts have been devoted to the simplification of the actual system. Due to limited space, they are not described here.

Finite element model and simulation results

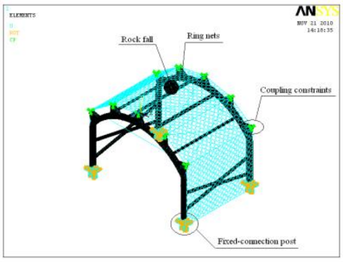

Fig.9 The numerical simulation model with boundary conditions

Tab.1 Material parameters of the FE model

Material Parameters	Modulus of elasticity(MPa)	Density (kg/m^3)	Yield stress (MPa)	C	P	Limited strain
steel	2.10e5	7850	500	40	5	0.15
cable	1700e5	7850	1770	40	5	0.03
Steel wire	1770e5	7850	1770	40	5	0.05
Rock fall	3.0e4	2500	--	--	--	--

In the finite element model, the ring nets are modelled by the beam161 element, the rock fall is modelled by the solid164 element, the cable is modelled by the link160 element and the steel vaulted structure is modelled by the shell163 element [3]. The boundary conditions and the numerical simulation model are shown in Fig. 9. The basic materials parameters are listed in Tab.1. Finally whenever contact occurs between the boulder and the ring nets or structure, a dynamic friction coefficient f_d =0.8 is assumed, which defines the dissipative contact model.

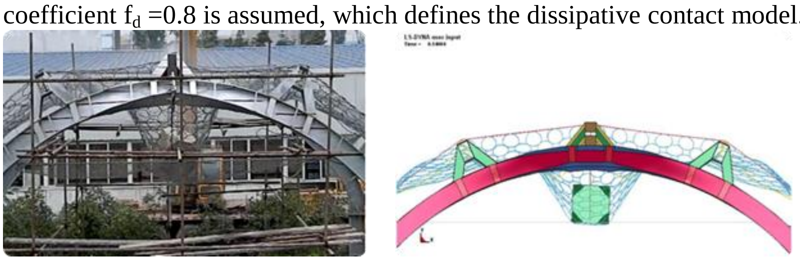

Fig.10 The flexible rock shed deformation obtained by the numerical simulation and the test when the rock-fall falls in the lowest point

The predicted deformation is compared to the testing measurement when the rock falls in the lowest point in Fig. 10. The maximum system deflection is 2.041m and the stop time is 0.128s from the simulation. However, the numerical results are somehow overestimated (10% in terms of limit deflection and time) by the present model. That is because the ring nets are loosely connected to the steel vaulted structure which was not accurately accounted for in the finite element model. Nevertheless, the results of the numerical simulation are in fairly good agreement with the experimental data.

CONCLUSIONS

The testing procedures cannot provide complete information about the absorption energy in the individual components as well as reactions at the support. Furthermore, full-scale field tests are time and cost intensive. The numerical methods are suitable for design or optimization purposes or for parametric analyses for the flexible rock-shed.

References

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