【III－19】

Constitutive modeling of friction damper for numerical simulation of long-span pocket-type rock-net

Long-span Pocket-type Rock-net,
Finite element analysis,
LPR Brake Model

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1. Introduction

Rockfall is an important geo-hazard of mountainous terrain and is receiving increased attention. The flexible type of rockfall protection structures such as pocket-type rock-nets have been the centre of attraction over the past decade, particularly for low to medium impact energy scenarios. A rock-net structure intercepts (catches) the falling rock block/s by dissipating the impact energy mainly by the large deformation of net-mesh and cables (wire ropes). Introduction of energy absorbing (dissipating) system such as a brake element (friction damper) has appreciably improved the performance of the system. The brake element is designed in such as way that it just slips when a predetermined value of tension in the cable, that it is installed with, exceeds; thereby dissipating an extra energy by its slippage, and sometimes by its permanent deformation.

In Japan, with some dozen of 1:1 prototype, field test verification over the past couple of years, an innovative and award-winning rock-net structural system named as "Long-span Pocket-type Rock-net" (hereafter referred as LPR structure) has been introduced into practice. The LPR structures, with spans (post-to-post) normally supposed above 10 meters (proposed for the time being up to 30 meters with the corresponding energy capacity of 400kJ) are in fact, an improvement over the prevailing shorter span pocket-type rock-nets (PR) with spans limited to 3 or 5 meters. The steel structure of LPR consists of net mesh/module, reinforcing cables, net-supporting sag cable in turn supported over the posts, and all the cables and post-supporting guys are ground to anchors with the appropriate arrangement of brake elements. Currently, the U-bolt type friction dampers (hereafter referred as LPR-UF damper) with specified brake load limits of 50 kN and 90 kN have been manufactured and tested.

The usual method of full scale test is really costly, time consuming, and in many ways less detailed to explain the actual mechanics of the structure. Further, the simplified analytical structural modeling and analysis method cannot help to define the behavior of the system which involves a complex interaction of various structural components. Fortunately, an alternative reliable solution exists, which underlies in numerical simulation such as finite element method. In numerical modeling, the success lies largely on the definition of constitutive models and their parameters. While doing so for LPR structure, unlike other structural components, the situation is different in the case of brake element. We do agree that taking care of the changed behavior of the LPR-UF damper in dynamic loading conditions, the element has been tested by the full-scale falling weight impact test [Fig.1]. Nevertheless, it has already been established that there is a number of chances of variation in the behavior of a structure involving (state- and rate- dependent) friction [1, 2]. Therefore, we also dedicated a part of our research for the detailed study on the constitutive modeling of the LPR-UF damper. This paper reports the fundamental study of the same.

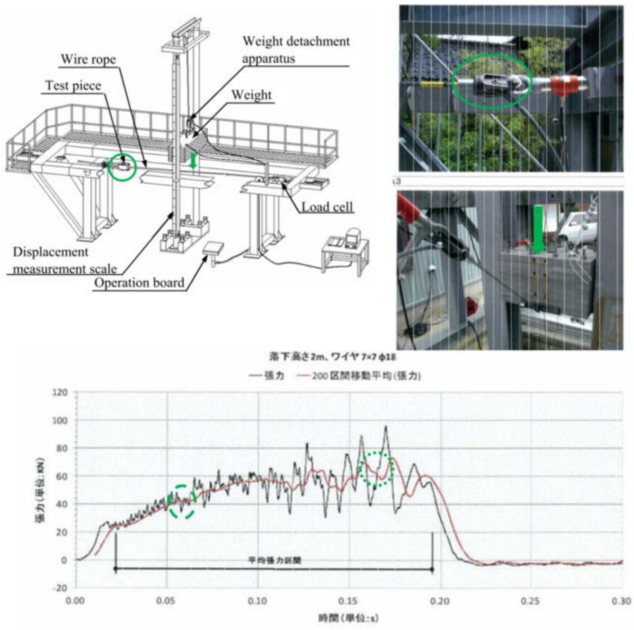

Fig.1: LPR-UF damper full-scale impact test (Result: brake tension: 50 kN and slippage = 0.5 m): Courtesy: BESAFE Co.

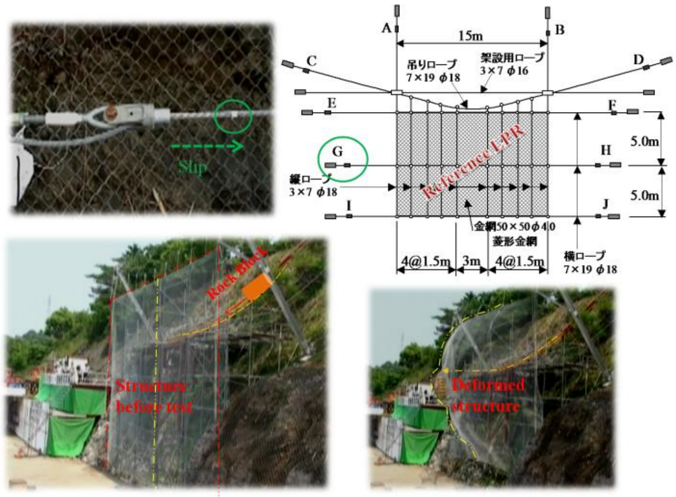

Fig.2: Reference case LPR structure and its full scale test scenario (Results for cylinder impact of 150 kJ: Maximum slip at H = 134 mm, Maximum out-of-plane displacement: 3.4 m, Maximum Tension at H = 94 kN at about 0.3 second): Courtesy: Daiichi Co.& Nihon Protect Co.

It is noteworthy to inform here that, numerically simulating the out-of-plane deformation of net is also a challenge. But, we have already addressed this (shall be found somewhere) macroscopically by the finite element shell modeling, with its constitutive parameters determined from the net mesh (panel) test, and regarding the simulation of flexural rigidity influenced by the section geometry, we have verified, through parametric back analyses, that the full scale test results may be simulated simply when the shell thickness (calculated from the weight equivalence of the real net used in FST) be halved. With this very assumption/modification over previous study [3], we have worked further analyses on LPR structure.

2. Methodology

A case of LPR structure, the behavior of which was studied by FST [Fig.2], was taken as a reference case (hereafter referred as RC-LPR structure). The structure was then modeled in the platform of LS-DYNA, which is assumed to be sufficient to conduct the nonlinear dynamic finite element analyses of large deformation structures subjected to transient dynamic loads. The net was modeled with Belytschko-Tsay Shell (with 2 through thickness integration points) finite element mesh, as a computationally efficient alternative to the Hughes-Liu Shell element. The cables were modeled with 2-node Discrete Beam (Cable) elements while the posts were modeled with Beam/truss element. The adopted material models for net, cables and post are respectively, Fabric (Mat_034), Cable Discrete Beam (Mat_071) and Plastic Kinematic (Mat_003). As per their calibration, for cables, the nonlinear stress-strain curve obtained from the laboratory test itself was assigned while for net and post, the specified constitutive parameters were assigned in the inbuilt models. Regarding modeling of the LPR-UF damper, we assumed it be modeled as a bar (truss) element of appropriate constitutive law such that its axial elongation may equivalently represent the brake slippage. Based on the physical observation as well as the available test performance, we assumed that the plastic kinematic hardening model may represent the behavior of the damper. However, when we saw difference in the role of friction damper in isolation, and when installed with LPR structure, we thought that the same set of constitutive parameters or even the same model may not work. Therefore, we are trying to fix the constitutive model of the damper by numerical parametric back analyses at LPR-structure level, and also with the analytical and numerical modeling at damper-element level, starting from scratch. Furthermore, we tended to realize that the existing damper design or installation should be improved to make the structure more efficient (optimal). We call the constitutive model thus searched for as the “LPR Brake Model/Law”.

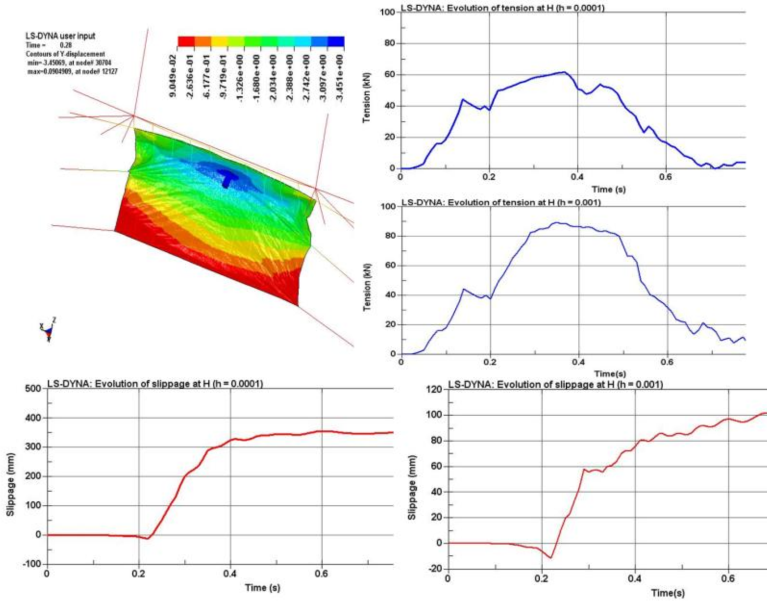

Fig.3: Few of the results of numerical parametric study on RC-LPR structure for the friction brake constitutive law

3. Results and discussion

3.1 From numerical parametric study at LPR-structure level [Fig. 3]

Assuming the plastic kinematic hardening rule to represent the constitutive law of the LPR-UF damper, a number of parametric analyses were carried out with varying hardening parameter (E_t = h. E; h from 0 to 0.1). The analyses also included the hardening parameter determined from the full scale test of damper (Fig. 1: some 20 kN rise in tension after brake for 500 mm of slippage), and also that of the full scale test of LPR reference case (Fig. 2: some 40 kN rise in tension for 134 mm of slippage). We observed that the kinematic hardening model may predict the slippage in the expected range. Analyses for various energy levels and, also for high strength material prospect with a fixed hardening parameter; for example obtained from the back analysis of the tested reference case of LPR, result to almost the same range of cable tension and slippage. To verify the role of damper in LPR, an analysis of high strength material, for instance, (results not shown) reveals that without braking provision, the maximum tension in the cable is around 150 kN, while it is limited to only 50 kN when a damper with parameter h = 0 is installed! This exhibits possibility of very efficient impact energy dissipation by improving the brake law.

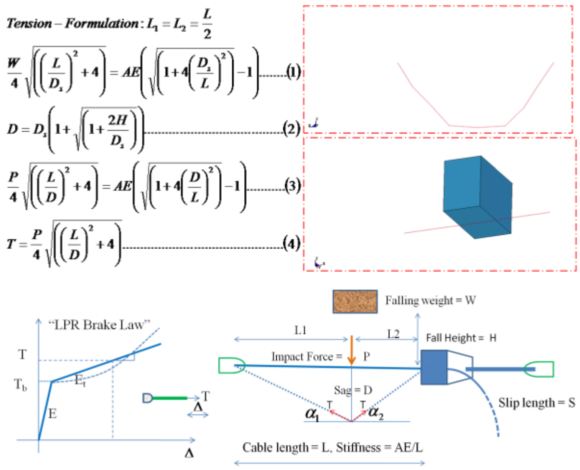

Fig.4: Analytical and numerical models, and formulation towards the development of LPR-UF damper constitutive model: “LPR Brake Law”

3.2 From analytical and numerical modeling at element level [Fig. 4]

Analytically, we utilized equilibrium-, compatibility-, constitutive- equations, and the principle of strain energy at falling weight impact of a cable element to obtain the relation for its tension (without brake device). Assuming that the difference in the value of this tension and the specified value of breaking tension of damper should correspond to the damper slippage or to the energy dissipation by damper, the constitutive relation of damper is believed to be established. Numerically, the isolated cable system in analytical study (complying with the past test situations) was numerically modeled by the discrete beam finite elements. When an assumed constitutive law, and parameters, leading to “LPR Brake Law”, is assigned to it and the evolution of tension in the cable is compared with that obtained from the test, this shall verify the law thus devised. For the purpose of studies, analysis with the impact load applied pseudo-statically was also studied. The basic models are shown in the referred figure.

4. Conclusions

- Friction damper can play a dominant role in dissipating impact energy of rockfalls over a rocknet structure.
- The behavior of friction damper is susceptible to variation, so its installation should be very carefully handled.
- Similarly, the constitutive law or the constitutive parameters of friction damper should not be taken as a constant entity. Careful judgment/intuition, calibration and verification are necessary while fixing the model.
- The existing design of the U-bolt friction damper seems to have the scope of improvement or modification for optimization.

After finalizing the “LPR Brake Model”, we aim to exercise the brake simulation also by micro-modeling of the slip-interfaces.

References

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