1. INTRODUCTION

The increasing frequencies of typhoons and localized torrential rainfall events are associated with sediment disasters involving debris flow (DF) [Marutani et al., 2018] and large woody debris (LWD) [Gasser et al., 2019]. In Japan, preventative facilities have been built on the fluvial fans; one such structure is like a steel open Sabo dam [Armanini et al., 1991; Mizuyama et al., 2008]. This dam facilitates normal sediment transport via appropriate spacing of the pipes [Mizuyama et al., 2010] and effectively entraps DF and/or LWD [Piton & Rocking, 2016a]. Moreover, the maintenance cost is low, because it is unnecessary to remove sediment.

Recently, a new steel open Sabo dam like the plane grid-type was developed as shown in Fig. 1. This dam can reduce the steel volume required rather than the current steel open dams dramatically. Steel pipe beams are mounted in sleeve pipes (hereafter, so called as a sleeve pipe beam) set into a buttress and, as such, the redundancy of the dam is greatly increased [Piton & Rocking, 2016b]. However, the load-carrying capacity of this dam has not yet been investigated.

The past studies on local deformation of steel pipes under impact load have been investigated by many researchers, for instance, Ellinas et al., (1982), Jones et al., (1992) and Shiraishi et al., (2002). Especially, Hoshikawa et al., (1995, 1996) conducted drooping weight tests using a hemispherical device and developed an impact evaluation method for steel pipes. However, these studies featured both ends-fixed conditions, and the steel pipes were not mounted in sleeve pipes. Also, although the modified Ellinas...
expression to measure the local deformation of a steel pipe beam under impact load has been used in Japanese design [NILIM, 2016; Sabo & Landslide Technical Center, 2009], no study has explored whether this is appropriate for sleeve pipe beams. In this study, the full-scale static load test of a sleeve pipe beam is first performed to examine the load-carrying capacity [Kokuryo, et al., 2018]. Second, a FEM analysis is executed to estimate the load-carrying capacity of steel pipe beams [Sonoda, et al., 2016, Kokuryo, et al., 2019]. Finally, a new design expression for a sleeve pipe beam is proposed by applying the modified Ellinas expression.

2. SLEEVE PIPES

The sleeve pipes connect the steel pipes with the concrete foundation, improving the durability of the entire structure, because of an interaction effect. Initially, the sleeve pipes are set in concrete, and the steel pipe is then slid into the sleeve pipes. Thus, there must be some clearance between the sleeve and the steel pipe as shown in Fig. 2, which may become detached after a disaster. If the steel pipe is simply embedded in concrete, the insertion length of the pipe is larger than the outside diameter; it is in fact more than twice the diameter \((D)\) (e.g., \(L_s=406.4 \text{ mm} \times 2=812.8 \text{ mm} \approx 2D\)). The relationship between the drawing force \(f\) and the drawing resistance \(R_f\) described below refers to Fig. 3.

2.1 Maximum load of the steel pipe beam at both-fixed-ends

When the steel pipe is assumed to be a both-ends-fixed beam, the maximum load \((P_{\text{max}})\) is computed by the collapse mechanism neglecting the local deformation at the loading point as follows:

\[
P_{\text{max}} = \frac{8M_r}{L_s} \quad (1a)
\]

\[
M_r = \sigma_f Z_r \quad (1b)
\]

\[
Z_r = \frac{D^4}{6} \left[1 - \left(1 - \frac{2t}{D}\right)^3\right] \quad (1c)
\]

where \(M_r\) : the plastic moment, \(\sigma_f\) : the yield stress of the steel pipe, \(L_s\) : the span length \((L_s=3,500 \text{ mm})\), \(Z_r\) : the plastic section modulus, \(t\) : thickness.

2.2 Drawing force of the sleeve pipe beam

The drawing force of the steel pipe \((f)\) is:

\[
f = \frac{P_{\text{max}}}{2} \sin \theta_1 \quad (2a)
\]

\[
\theta_1 = \theta_i + \theta_{ra} \quad (2b)
\]

\[
\theta_2 = \tan^{-1}\left(\frac{S}{L_s}\right) \quad (2c)
\]

\[
\theta_{ra} = \frac{1.355}{(D/t)} \quad (2d)
\]

where \(\theta_1\) : the angle after local deformation of a steel pipe, \(\theta_i\) : the inclination of a steel pipe inserted into a sleeve pipe, \(S\) : the clearance between the sleeve and steel pipes, and \(\theta_{ra}\) : the allowable plastic rotation angle of the steel pipe [STC, 2009].

2.3 Resistance force inside a sleeve pipe beam

The resistance force inside a sleeve pipe beam \((R_f)\) is:

\[
R_f = \mu P_{\text{max}} \lambda \quad (3)
\]

where \(\mu\) : the friction coefficient between the steel pipes (0.23 in Japanese design [STC, 2009]), and \(\lambda\) : the surface friction resistance (here, assumed to be 1/4 for steel pipe). Table 1 lists the test case and verification.
3. EXPERIMENTAL SETUP

3.1 Static load test

A test piece was manufactured; the ends of a steel pipe were inserted into sleeve pipes embedded in concrete on both sides, as shown in Fig. 4. Then, a hemispherical load was statically applied to the center of the steel pipe using a static loading machine. Fig. 5 shows a panoramic view of the static test device and a close-up of the loading position. The measured items were the load at the center point, the displacements, and the strains. The load was measured by a load cell attached to the upper part of the load body, and displacements were measured at four points on the steel pipe. The strains were measured at four points close to the center of the steel pipe, and at another four points in the sleeve pipe to observe horizontal movement of the steel pipe beam, as shown in Fig. 4.

3.2 Test pipes

The two steel pipes (#1 and #2) used in the test are carbon steel employed for general structures (JIS G 3444). They are the same diameter \( D = 406.4 \, \text{mm} \), the same span length \( L_s = 3,500 \, \text{mm} \) with two different thicknesses \( t = 7.9 \, \text{mm} \) and \( 12.7 \, \text{mm} \), and the insertion length \( L_i = 1,000 \, \text{mm} \), as shown in Fig. 4 and Table 2.

In practice, the pipe diameter ratios (diameter/thickness) of 30–60 are used in a steel open dam; The pipes used in the test had ratios of 51 and 32. The sleeve pipe of 457.2 mm in diameter, thus larger than the steel pipe, and 9.0 mm in thickness, was employed. The sleeve pipes and the concrete foundation are in close contact, while clearance is required between the sleeve pipes and the inserted steel pipe (16.4 mm on either side in the present case). The concrete foundation was standard, as shown in Table 3.
4. EXPERIMENTAL RESULTS

4.1 Case 1 \((D = 406.4 \text{ mm}, t = 7.9 \text{ mm})\)

Fig. 6 (a), (b) and (c) show the deformation profiles of the pipe beam at the loads of 100, 200 and 250 kN, respectively. **Fig. 6 (a)** shows beam did not deform radically at 100 kN. **Fig. 6 (b)** shows the deformation profile of the pipe at 200 kN. **Fig. 6 (c)** shows the moment at which the ratio of local deformation \(\delta_e\) to pipe diameter \(D\) (it is termed \(\delta_e/D\)) attained 40%, and 250 N, which is the repair limit state which is important in terms of definition of repair of pipe \([STC, 2009]\).

**Fig. 7** shows the relationship between the load and deformation at the centre of steel pipe beam, in which the displacements of the upper- and under-surfaces at the center are shown. Therefore, the local deformation is depicted as the difference \((\delta_u - \delta_l)\) between upper-surface displacement \((\delta_u)\) and the under-surface displacement \((\delta_l)\).

**Fig. 8** shows the relationship between the load and deformation of the ends of the steel pipe, in which the under-surface displacements at the center and at the end are shown. Therefore, the real beam displacement at the center is given as the subtraction \((\delta_c - \delta_r)\) of the end settlement \((\delta_c)\) from the under-surface displacement \((\delta_r)\). The real beam displacement \((\delta_c)\) was also compared with the theoretical deflection which is calculated by the simply supported steel pipe as follows:

| Item          | Diameter (mm) | JIS standard | Thickness (mm) | Tensile strength (N/mm²) | Yield stress (N/mm²) | Elongation (%) | Young’s modulus (N/mm²) |
|---------------|---------------|--------------|----------------|--------------------------|----------------------|---------------|-------------------------|
| #1 Steel pipe | 406.4         | STK400       | 7.9            | 461                      | 318                  | 37            | 2.0x10⁵                  |
| #2 Steel pipe | 406.4         | STK490       | 12.7           | 533                      | 425                  | 37            | 2.0x10⁵                  |
| Sleeve pipe   | 457.2         | STK490       | 9.0            | 541                      | 393                  | 36            | 2.0x10⁵                  |

**Table 3** Concrete foundation

| Compressive strength (N/mm²) | Slump test (mm) | Max. size of coarse aggregate (mm) | Species  |
|------------------------------|-----------------|-----------------------------------|----------|
| 18                           | 80              | 20                                | BB       |

![Fig. 6 Deformation profiles at each loading (Case 1)](image1)

![Fig. 7 Relationship between load and displacement (Case 1 : Local deformation)](image2)

![Fig. 8 Relationship between load and displacement (Case 1 : Real beam displacement)](image3)
where $E$ : Young’s modulus and $I$ : the sectional secondary moment of the steel pipe.

Table 4 compares the results of the sleeve pipe beam with the simply supported beam (i.e., the theoretical deflections $\delta_{th}$) at initial stage of loading. The displacement of the under-surface at the center ($\delta_{ts}$) is larger than the theoretical value. However, settlement ($\delta_{s}$) occurs at the end of the steel pipe commencing at initial loading, and to approximately 150 kN, the real beam displacement ($\delta_{r} = \delta_{ts} - \delta_{s}$) is in good agreement with the theoretical deflection of a simply supported beam. Therefore, during initial loading, both the sleeve pipe and simply supported beams exhibit very similar deformation behavior. However, when the load attains 190–200 kN, the only displacement increases. Furthermore, as the increase of load, the displacement also increased, and the maximum load $P_{m1}$ was approximately 750 kN.

An examination of the load-carrying capacity of steel pipes supported in different ways revealed that the maximum load $P_{m1}$ of the sleeve pipe beam (750 kN) lay between the full plastic loads (collapse loads) of the simply supported beam ($P_{m1}$)(456 kN) and the both-ends-fixed beam ($P_{m3}$)(912 kN), but closer to the latter value. The collapse loads of the simply supported and both-end-fixed beams were calculated using the following equations, respectively.

$$P_{m1} = \frac{8M_{p}}{L}$$  \hspace{1cm} (5)

These results imply that the support afforded by the sleeve pipe at initial loading was close to that of a simply supported beam, but, as the load increased, the load-carrying capacity became closer to that of a both-ends-fixed beam. Therefore, the maximum load of the sleeve pipe beam (approximately 750 kN), $P_{m1}$, corresponds to approximately 82% of the full plastic load (912 kN) of a both-ends-fixed beam, $P_{m3}$. This may be caused by the reason that the both-ends of sleeve pipe beam may become a semi-fixed support including a little rotation which is not complete rigid.

4.2 Case 2 ($D = 406.4$ mm, $t = 12.7$ mm)

Fig. 9 shows the condition of the test piece when loads of 200, 600 and 900 kN (deformation rate 40%) were applied, respectively. As with Case 1, the pipe deformed as the load was applied, but the detailed result is different. In Case 1, because of the thinner thickness of the pipe ($D/t = 51$), the deformation was more intense than in Case 2. Furthermore, in Case 2, the deformation was small even with an equivalent load because of the thicker thickness ($D/t = 32$).

Figs. 10 and 11 indicate the relationship between the load and displacement at the center of the steel pipe and the theoretical deflections calculated using Eq. (4), respectively. In Case 2, given the thickness of the steel pipe, the load was raised, but the experiment ceased at approximately 1,200 kN due to the limitation of the loading device. The displacement at the center of the steel pipe during the test ($\delta_{r} = \delta_{ts} - \delta_{s}$) is shown
in Table 5. Up to 400 kN, the deformation was very similar to that of a simply supported beam.

Moreover, the relationship between the load and displacement within the applicable load range was similar in Case 1. In other words, when the load was increased to about 500 kN, the displacement also increased, but when the load approached 500-550 kN, the displacement continued to increase only because of sliding. Therefore, in Case 2, displacement at initial loading, which ignores displacement of the end of the pipe, and also exhibited behavior similar to that of a simply supported beam. However, sliding exerted a stronger influence.

As for Case 2, the full plastic load of the simply supported beam and the both-ends-fixed beam, \( P_{p_{2z}} \) and \( P_{p_{2z}} \), were calculated using Eq. (5) and (6) and were 956 and 1,912 kN, respectively. Thus, within the load range of the test (approximately 1,200 kN), the load-carrying capacity was superior to that of a simply supported beam.

### 4.3 Sliding amount of a sleeve pipe

Fig. 12 shows the horizontal movement of the steel pipe in Case 1. When the load increased, sliding...
increased simultaneously. When approximately 200 kN [Fig. 12(a)] was applied, displacement increased; the pipe slid 20 mm. As the load increased, displacement attained approximately 50 mm at the maximum load of 750 kN [Fig. 12(b)]. However, this is only 5.0 % of the insertion length into the sleeve pipe (L = 1,000 mm) in length, because 2.8 % of the half-span length of the steel pipe (L/2) is 1,750 mm. Therefore, it is considered that the effect of sliding amount on the deformation of sleeve pipe beam is small.

However, when in design sleeve pipes that must withstand boulder collisions, it is necessary to consider steel pipe deformation and sliding caused by the clearance between the steel and sleeve pipes. Finally, these results suggest that this requirement can be met using the next new design expression in which a sleeve pipe beam should be treated as semi-fixed ends, not complete-fixed ends.

5. FEM ANALYSIS

The objective of this analysis is to reproduce (simulate) the load test to verify the applicability of the FEM analysis up to the maximum load in Case 1, as well as the one of Case 2, which could not be measured in the test.

5.1 Analytical model

The analysis was carried out by using the non-linear analysis code MSC Marc (1971) based on the Finite Element Method (FEM). Considering the symmetry of the test piece in the load test, the model was used the 1/4 scale that is same to experiment model, which means the span length of 1/2 and the diameter of 1/2, as shown in Fig. 13.

Regarding the type of analysis elements, the steel pipe members (between beam and sleeve), the concrete body, and the load body were defined as a shell element, a solid element, and a rigid body, respectively. Also, as boundary conditions, the base of the concrete body was completely fixed, the concrete body and sleeve pipes were completely fixed to each other, and a coefficient of friction of 0.3 was set, considering the influence of friction between the contact surface of the steel pipe beam and sleeve pipe.

5.2 Material properties used in the analysis

The material properties used in the analysis are shown in Table 6. The Poisson’s ratios of the pipe and concrete material were set to 0.3 and 0.194, and the specific weights to 77.0 kN/m$^3$ and 22.5 kN/m$^3$, respectively. For the stress-strain relationships of pipe materials STK 400 and STK 490, the true stress-true strain relationships were used.

5.3 Simulation results

Fig. 14(a) and (b) show the simulation results of Case 1 and Case 2 by FEM analysis, respectively. A comparison of the analysis and the test results shows that the FEM analysis simulated accurately to

![Fig. 13 Analytical model](image)

**Table 6 Material properties of steel pipe and concrete**

| Name          | Material | Young’s modulus (N/mm$^2$) | Poisson’s ratio | Tensile strength (N/mm$^2$) | Yield stress (N/mm$^2$) | Elongation (%) | Specific weight (kN/m$^3$) |
|---------------|----------|---------------------------|----------------|-----------------------------|------------------------|----------------|---------------------------|
| #1 Steel pipe | STK400   | 2.0×10$^4$                | 0.300          | 461                         | 318                    | 37             | 77.0                      |
| #2 Steel pipe | STK490   | 2.0×10$^4$                | 0.300          | 533                         | 425                    | 37             | 77.0                      |
| Sleeve pipe   | STK490   | 2.0×10$^4$                | 0.300          | 541                         | 393                    | 36             | 77.0                      |
| Concrete material | BB type | 2.0×10$^4$                | 0.194          | -                           | -                      | -              | 22.5                      |
the test results in both cases, from the behavior at the initial stage of loading including the influence of sliding to the displacement increase as the load is increased. It was confirmed the computational results are almost good agreement with the test results.

Table 7 shows a comparison of the maximum loads of test and analysis values. Although the maximum load of Case 2 has not obtained by the test due to the limitation of loading device, FEM analysis was able to obtain as 1,821 kN which is almost near the fixed beam. The collapse loads of the simply supported beam and the both-ends-fixed beam, calculated with Eq. (5) and (6), are also listed.

6. Proposal of new design formula for sleeve pipe beam

It is proposed that a new design formula for a steel pipe beam mounted in sleeve pipe (hereafter, it is called as a sleeve pipe beam) is expressed by applying the modified Ellinas expression, in which both fixed ends are changed into the semi-fixed ends, as shown in Fig. 15(a). Therefore, Table 8 shows the bending moment diagram, the equation of maximum load and its value of the sleeve pipe beam compare with those of the simply supported beam and the both-ends-fixed beam.

6.1 New design formula of sleeve pipe beam

6.1.1 Load corresponding to local deformation

The load \( P_l \) corresponding to local deformation of a sleeve pipe beam, as the same as a steel pipe can be determined by referring to the modified Ellinas expression [Hoshikawa, et al. 1995, Ishikawa, 2009] as follows.

\[
P_l = \frac{1}{4} K \delta_s A \left( \frac{\delta_{ss}}{D} \right)^{0.8} \quad (6a)
\]

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**Table 7** Comparison of the maximum loads by test and analysis

| Case    | Test (kN) | Analysis (kN) | Simply supported beam (kN) | Both-ends-fixed beam (kN) |
|---------|-----------|---------------|-----------------------------|---------------------------|
| Case 1  | 750       | 795           | 456                         | 912                       |
| Case 2  | 1,200*    | 1,821         | 956                         | 1,912                     |

[Note] *means the value stopped due to loading device, not the maximum load.

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**Fig. 14** FEM analysis results comparing with test result

**Fig. 15** Deformed steel pipe shape and collapse mechanism of sleeve pipe beam
Table 8 Comparison of the maximum loads by different supported beams

| Bending moment diagram | Simple support beam | Both-ends-fixed beam | Sleeve pipe beam (Semi-fixed ends) |
|------------------------|---------------------|----------------------|-----------------------------------|
| Equation               | $P_{pa} = \frac{4M_{p}}{L_s}$ | $P_{pa} = \frac{8M_{p}}{L_s}$ | $P_{pa} = \frac{4(M_{pa} + M_{pc})}{L_s}$ |
| Case 1                 | $P_{pa1} = 456 \text{kN}$ | $P_{pa2} = 912 \text{kN}$ | $P_{pa2} = 795 \text{kN}$ ($\beta = 0.87$) |
| Case 2                 | $P_{pa2} = 956 \text{kN}$ | $P_{pa2} = 1,912 \text{kN}$ | $P_{pa2} = 1,812 \text{kN}$ ($\beta = 0.95$) |

6.1.2 Collapse load of sleeve pipe beam ($P_c$)

If both ends of the sleeve pipe beam are assumed as semi-fixed, the collapse load can be obtained by the collapse mechanism of sleeve pipe beam in Fig. 15(a).

$P_c = \frac{4}{L} (M_{pa} + M_{pc})$ (7a)

$M_{pa} = \beta D^3 \sigma_s \varepsilon t$ (7b)

$M_{pc} = \frac{4}{3} \sigma_s \varepsilon [a b^2 - (a - t)(b - t)]$ (7c)

$a = \frac{D}{[2(1 - 1/4 \alpha^2 - 3/64 \alpha^4 - 15/768 \alpha^6)]}$ (7d)

$\alpha^2 = 1 - \left(\frac{b}{a}\right)^2$ (7e)

$b = \frac{(D - \delta_e)}{2}$ (7f)

Herein, when the plastic moment is calculated, it is assumed that the cross-section of the steel pipe is circular before deformation and is elliptical after deformation, as shown in Fig. 15(b). Where, $L$: the span length, $M_{pa}$: the plastic moment of the semi-fixed end, $M_{pc}$: the plastic moment of the center point, $a$: the largest radius of the ellipse, $b$: the shortest radius of the ellipse, $\beta$: semi-fixed factor which is determined as the ratio of the value by FEM analysis with the one of both-ends-fixed beam, $\beta = 0.87$ and 0.95 in Cases 1 and 2.

6.1.3 Maximum local deformation of sleeve pipe beam

The maximum local deformation of steel pipe ($\delta_e$) is attained when the load ($P$) and the collapse load of the sleeve pipe beam ($P_c$) are equal, and is found as:

$\delta_e = D \left(\frac{16}{LK^2} \left(\beta D^3 t + \frac{4}{3} [a b^2 - (a - t)(b - t)]\right)\right)^{1/2}$ (8)

The maximum deformation ($\delta_e$) is computed by assuming values for “a” and iterating until the value converges.

6.2 Energy absorption

6.2.1 Energy absorption by local deformation

The energy absorption ($E_a$) prior to the maximum local deformation of the steel pipe ($\delta_e$) is expressed as:

$E_a = \frac{1}{4} K \sigma_s \varepsilon t^2 \frac{\delta_e^{1.5}}{1.8D^{3/2}}$ (9)

6.2.2 Energy absorption by plastic deformation of sleeve pipe beam

The energy absorption by plastic deformation of a sleeve pipe beam is computed as follows:

$E_w = P_c \delta_{pa}$ (10a)

$\delta_{pa} = \frac{\theta_{pa}}{(L/2)}$ (10b)

$\theta_{pa} = \frac{1.355}{(D/t)}$ (10c)

where $P_c$: the collapse load of the sleeve pipe beam, $\delta_{pa}$: the allowable plastic deformation, $\theta_{pa}$: the allowable plastic rotation angle (STC, 2009).
6.3 Verification of new design formula

Fig. 16 shows the relationships between load and deformation of Case 1 and 2 comparing the new design expression (hereafter, design) with test and analysis results, respectively. The energy absorptions of design, test and analysis were illustrated by the areas of load-deformation curves as shown in Fig. 16(a)–(f), respectively.

These results are summarized in Table 9. The energy absorptions by test (168 kJ) and analysis (210 kJ) in Case 1 were about 1.3~1.7-fold higher than the one by the design (125 kJ), respectively.

In Case 2, the energy absorbed by the analysis (773 kJ) was 2.8-fold larger than that of the design (270 kJ). The results confirm that the design remains conservative when the new design expression is adopted in the design of the sleeve pipe beam.
7. DISCUSSION

7.1 Maintenance of new plane grid-type dam
A steel open dam allows constant transport of normal amounts of sediment, and efficiently traps DF and/or LWD [Armanini et al., 1991].

The proposed new plane grid-type dam with sleeve pipe dam does not require a large area. Also, this new dam can trap DF and/or WDF from small, inactive, and usually dry catchments [NILIM, 2016; STC, 2009]. It is possible to construct the new grid-type dam even in geographically challenging regions.

The maintenance cost of the new plane grid-type dam will be decreased. If the sleeve pipe beam is damaged after DF, the pipe can be easily replaced. If there is no damage, it is easy to detach the steel pipe to remove DF and WD. Thus, this dam life is prolonged; Repair and reinforcement of this dam are very simple.

7.2 Problems with the new design formula
The scale of DF is recently becoming large and heavy due to the abnormal weather. The impulsive loads of debris flows have been so far examined by [Ancey et al., 2015; Faug., 2015; Song et al., 2015; Hübl et al., 2015; Poudyal et al., 2019]. The debris flow fluid force [Daido et al., 1994] and the boulder collision load [Mizuyama et al., 1979] have been evaluated. However, impulsive and/or impact load performance evaluations for a sleeve pipe beam have not been addressed. Therefore, it is needed to investigate the dynamic effects of a sleeve pipe beam. The limits of application of new design formula for a sleeve pipe beam should be explored by impact test or analysis in the near future.

8. CONCLUSIONS
This study investigated the load-displacement relations of steel pipe beams supported by sleeve pipe through a static load test and FEM simulation. Finally, a new design expression was proposed. The following conclusions were drawn from this study.
(1) It was found that the maximum load of the sleeve pipe beam was nearly equal to the one of both-ends-fixed beam from the viewpoint of the load-carrying capacity.
(2) At initial loading, the displacement at the center exhibited deformation behavior similar to that of a simply supported beam.
(3) At the halfway stage of loading, the only horizontal deformation noted was caused by the clearance between the steel pipe and the sleeve pipes. Then, as the load increased, the sleeve pipe beam became similar to those of a both-ends-fixed beam.
(4) It was clarified that the maximum load (1821 kN) of the # 2 sleeve pipe beam was estimated by the FEM analysis, although it was not obtained by the test.
(5) A new design formula was proposed for a sleeve pipe beam by introducing the semi-fixed ends into the modified Ellinas expression.
(6) The dynamic problems (such as boulder collisions in debris flows) for a sleeve pipe beam should be investigated in the future.

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