Workshop for Young Researchers
Feb. 13, 2020 Tokyo Tech

A simple prediction method on the response of DCFP bearings under earthquakes based on energy

Jiaxi Li[1], Satoshi Yamada[2]

[1] *Tokyo institute of technology, li.j.ax@m.titech.ac.jp*
[2] *Tokyo institute of technology, yamada.s.ad@m.titech.ac.jp*

Abstract— **In this study, two friction models (precise and simplified model) of double concave friction pendulum (DCFP) bearings comprehensively validated by full-scale sinusoidal dynamic tests under various conditions were proposed. In addition, response analysis based on previous studies was conducted using the friction models under various unidirectional earthquake excitations and the accuracy of using the simplified model on the response analysis was studied. Based on these work, a simple prediction method is proposed which can relate the response displacement of the isolation system to the ground velocity by energy with sufficient accuracy. This method is more accurate than the original design method introduced in ASCE and at the same time easier to be applied in design than response analysis.**

I. INTRODUCTION

DCFP bearing, which is a type of base isolation technique that detaches structures from the ground to help stabilize buildings from earthquakes, are widely used in earthquake-prone regions. The composition of it is shown in Fig. 1.

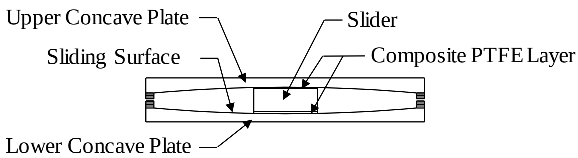


Fig. 1 Composition of a DCFP bearing

In actual design process based on the ASCE/SEI7-16 [1], property modification factors which are used for setting the upper and lower bound friction coefficient will always make the necessary stiffness and required maximum displacement to design a building be overestimated a lot. To figure this, a simple but more accurate method on predicting the maximum response of buildings in earthquake is necessary.

II. FRICTION MODEL

A. *Temperature Computation Method*

Two friction models are proposed considering pressure, velocity and temperature dependency as precise and simplified model. The temperature calculation method of them are shown in Fig. 2. Since the simplified model has much less temperature monitor points than the precise model, the simplified model has much higher calculation speed.

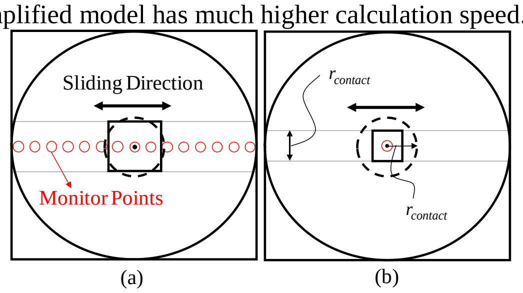


Fig. 2 Calculation method of representative temperature for (a) Precise model and (b) Simplified model

B. *Verification Tests and results*

Dynamic tests shown in TABLE 1 were conducted to validate the friction models under various situations.

TABLE I
TEST PROCEDURE OF VERIFICATION TEST (ASCE TEST)

Spec.	Test	σ	Amp.	Vmax	Period	Cyc.
num	num	N/mm^2	±mm	mm/s	s	num
φ300 & φ400	T01	60	268	392	4.26	3
	T02		10	15	4.26	20
	T03		100	146	4.26	3
	T04		200	293	4.26	3
	T05		268	392	4.26	3
	T06		400	585	4.26	3
	T07		400	585	4.26	3
	T08	40	400	585	4.26	3
	T09	80	400	585	4.26	3
	T10	30	440	644	4.26	1
	T11	90	440	644	4.26	1
	T12	60	300	439	4.26	20
	T13		268	392	4.26	3

The comparison of the first hysteresis curve between the friction models and the experimental results under both strong and weak excitations in Fig. 3 shows that both friction models have high accuracy.

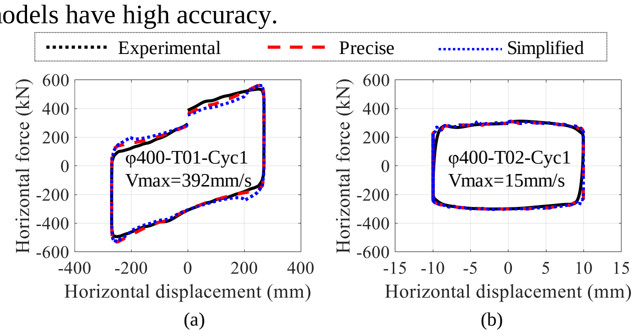


Fig. 3 Accuracy of Precise model and Simplified model under (a) Strong excitation (seismic) and (b) Weak excitation (wind-like)

III. RESPONSE ANALYSIS

A. *Mechanical Model*

The mechanical model used in the response analysis is shown in Fig. 4 considering both static and dynamic friction. Spring (a), (b) and (c) represent the restoring force, the elastic force of the entire system and the friction force respectively. To see the relation of the response and the earthquake records clearer, the structure is set as a rigid body.

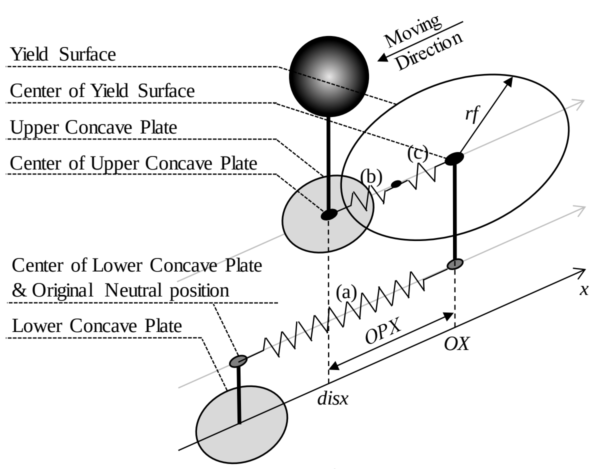


Fig. 4 Unidirectional Mechanical Model of a Rigid Structure with DCFPB

B. Input Earthquake Motion

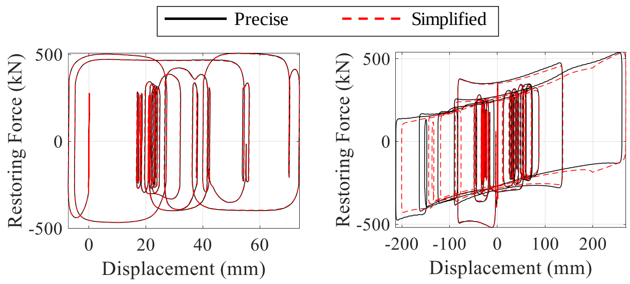
In order to see whether the simplified model can be used instead of the precise model in the response analysis and later as the analysis data base of the prediction method, earthquake inputs shown in TABLE II are selected. Each earthquake records are amplified to 4 input waves with PGV equals 0.25m/s, 0.50m/s, 0.75m/s and 1.00m/s.

TABLE II
INPUT EARTHQUAKE MOTION

Abv.	Earthquake.	PGV (m/s)	Duration (s)	Field
JKB	Kobe	0.893	30	Far
KNA	Kobe	0.373	41	Near
TC1	Chi-Chi	0.554	90	Near
NCC	Northridge	0.449	20	Far
LPG	Loma Prieta	0.447	40	Near
IVD	Imperial Valley	0.330	100	Near
TSD	Tohoku	0.545	180	Near
TIM	Tohoku	0.376	300	Near

C. Accuracy of Response Analysis Using Simplified Model

As shown in Fig. 5, the response analysis results using the simplified model are as good as that using the precise model under both strong and weak earthquake excitations.



(a) (b)

Fig. 5 Accuracy of the force-displacement curve by using simplified model under JKB earthquake: (a) PGV=0.25m/s; (b) PGV=1.0m/s

IV. A SIMPLE METHOD TO PREDICT THE RESPONSE DISPLACEMENT OF DCFPB UNDER EARTHQUAKE

A. A Prediction Method Based on Energy

By comparing the response history with the earthquake records under various earthquakes, it shows that the relation between the earthquake intensity ($\Delta GVm/\Delta t$) and friction coefficient of DCFP bearing (μ) can distinguish the calculation method of the response displacement as shown in Fig. 6, in which y_g is the ground displacement and y is the response displacement. As for the energy method, it is found that the response displacement can be related to the ground velocity by energy. Based on the maximum ground velocity change ΔGVm, the corresponding energy input can be predicted by eq. (1); Then, the amount of it that transfers to hysteresis energy ΔEh can be calculated by eq. (2); Finally, the response displacement can be calculated from ΔEh based on eq. (3).

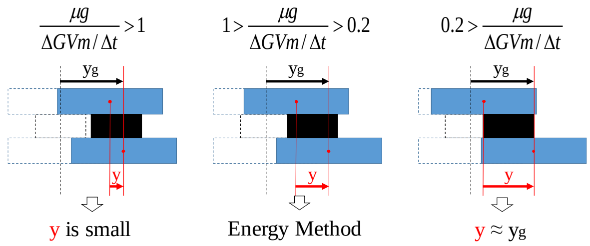


Fig. 6 Different response patterns of DCFP bearing

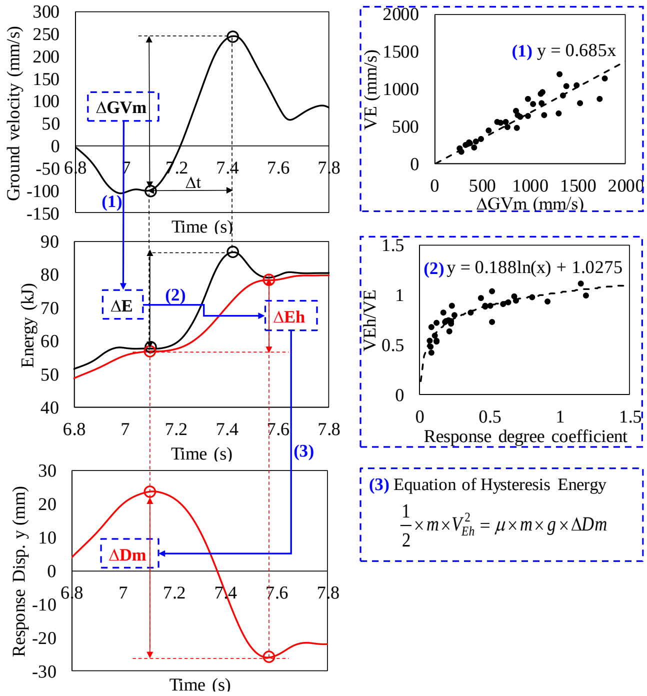


Fig. 7 Prediction Method Based on Energy (Energy Method)

B. Accuracy of the predicted response analysis

The accuracy of predicted response displacement under amplified earthquakes shown in TABLE II is shown in Fig. 8, which shows sufficient accuracy under all cases.

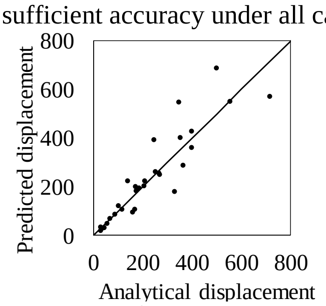


Fig. 8 Accuracy of predicted displacement

V. CONCLUSION

This study can provide new ideas for isolation design with DCFP bearings or even help refine the existed design code.

REFERENCES

[1] American Society of Civil Engineers (ASCE), 2016. Minimum Design Loads and Associated Criteria for Buildings and Other Structures, ASCE/SEI 7-16, Reston, VA.