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ELEVATOR CW DERAILMENT RESEARCH IN TAIWAN

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SUMMARY

A three-year research program utilized full-scale specimen tests and numerical analysis to study the mechanical behavior, damage types, and tie-bracket retrofit of elevator CW was conducted. Static full-scale tests on guide rail and guide shoes assembly was first performed. The main purpose is to identify the critical derailment loads and damage patterns of different guide rail systems. Shaking table tests on full-scale guide rails and CW assembly were next performed to study the design and retrofit programs for engineering applications. It was found that: (1) The 5-kg rail CW assembly for an 8-passenger car system could endure Peak Acceleration (PA) up to 600 gal before guide rails' deformation to exceed the guide shoes depth of 30 mm. The derailment of CW took place subsequently. (2) A 15-passenger car CW on an 8-kg assembly could endure PA up to 1200 gal without derailment or large rail deformation. (3) Rail brackets deformed significantly in contrast to the current design assumption of small deformation.

INTRODUCTION

Elevator design practices in Taiwan are strongly influenced by the Japanese industrial standards. Many design formula for seismic consideration in Taiwan follow what the Japanese developed in the 60' but did not made appropriate adjustment along with the latest seismic building codes advancements in Taiwan or Japan. As a result, starting from the 1998 Rae-Lei earthquake, elevator damage problem began to surface[1].In the 1999 Chi-Chi earthquake, many elevators suffered severe damage and resulted in delay of post-earthquake recovery operations to a great extent. In the epicenter area, there were 579 reported Counter Weight (CW) derailment and 341 reported passenger cart derailment.[1] It was discovered that most damage took place on the 5-kg/m (5K) guide rail systems. Fig. 1 illustrates the cross section of a 5K rail. The cross section is made of cold-formed sheet metal and is different from other higher rail grades, such as 8K and 13K, which are made from hot-rolled T section as shown in Fig.3. Because there is a lack of research data on the elevator performance in Taiwan, many building owners and architects have little idea what would be the appropriate retrofit method to prevent future damages by earthquakes.

USA experiences on the elevator safety in earthquakes started in 1964 after the Alaska earthquake [2]. But it was not taken seriously until the 1971 San Fernando earthquake, then the California government started

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to implement earthquake-resistant measures for elevators in schools and hospitals [3]. In the subsequent major earthquakes, it was found that although incidences of earthquake damage still happens, but the purpose to protect life safety of passengers has achieved [4,5]. Recently, there are also research work on using nonlinear FE to investigate CW system used in the USA[6] ¡C

A three-year research project to understand elevator problems were conducted. First performed was a full-scale static component test to understand interactive behavior between guide shoes and guide rails. Based on the experimental results, appropriate finite element models were built to predict behavior of different guide rail systems.[1] Full-scale shaking table tests on different CW systems were then performed to identify ultimate capacity of some commonly used elevator CW assembly in Taiwan.[7]

This paper will first describe CW design practices commonly used in Taiwan for earthquake forces and followed by in depth description of shaking table tests. Finally, the interpretation of the experimental result relating to recent building codes will be explained.

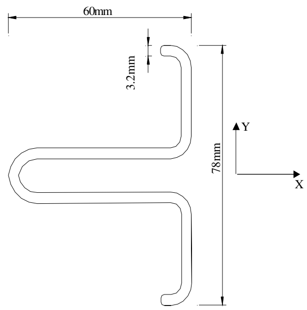


Fig.1 5K rail section

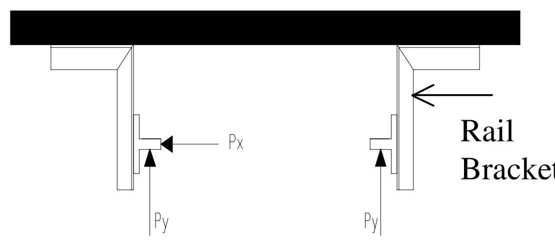


Fig. 2 Seismic Design Force on CW Rail

CW DESIGN PRACTICES IN TAIWAN

Seismic design for guide rails is to ensure impact force from the CW assembly on rails do not cause excessive stress and deformation on rails. Therefore there are formulae to consider effective impact force and allowable rail stress and deformation. The former is related to design force and the latter with rail material and section sizes. Because CW assembly is not connected to rails, impact force parallel to the plane of the CW, P_x, will be resisted by one rail only while perpendicular impact force, P_y, can be shared by two rails, as shown in Fig. 2. Therefore P_x is usually considered twice that of P_y and only P_x is designed for.

A CW may impact on rails at top and bottom guide shoes; therefore there is a different design force ratio for top and bottom impact points. In general, a force ratio of 0.4 : 0.6 is adopted in Taiwan to emphasize the larger impact force at the bottom guide shoes. Therefore, the design force on rails are expressed as:

$$P_X = F_H \times \Sigma \quad (1)$$

$$P_Y = \frac{1}{2} F_H \times \Sigma \quad (2)$$

where F_H is the horizontal seismic force and Σ is the force ratio.

If *IBC2000*[6] is considered for the design earthquake force, F_H can be expressed as:

$$F_H = \frac{0.4 \cdot a_p \cdot S_{DS}}{\frac{R_p}{I_p}} \left[1 + 2\frac{z}{h} \right] W = K_H W$$

where $0.4S_{DS}$ is the design ground acceleration which has two values of 0.33G and 0.23G in Taiwan's zone I and zone II. Therefore considering the worst design condition in Taiwan for elevator CW, the rail system should withstand an acceleration K_H equal to :

$$K_H = 0.33 \times 1.5(\text{for } a_p) \times 1.5(\text{for } I_p) \times 3(\text{for top floor}) \div 2.5(\text{for } R_p) = 1.5\ G$$

The stress(σ)and deformation(δ) on rails for those without intermediate stopper are calculated as:

$$\delta = \frac{11}{960} \times \frac{Pl^3}{EI}\,(cm) \tag{3}$$

$$\sigma = \frac{7}{40}\frac{Pl}{Z}\,(kg/cm^2) \tag{4}$$

where l is the distance between rail brackets and Z is the rail section modulus (cm^3). Equations (3) and (4) are based on a simplified three-span continuous beam model where loading at bottom guide in equation (1) or (2) is applied at the center of the center-span.

Fig. 3 illustrates the detail of guide-rail and guide-shoe. It is observed that A is the inserted depth of rail into a guide-shoe and C is the allowable tolerance. Therefore, the calculated rail deformation, δ, in equation 3 will be limited by:

$$\delta \le A - 1.0 \quad (cm) \tag{5}$$

assuming bracket deformation of 5 mm or less. The 5K and 8K rail system usually has an A equals to *2.5 cm*, therefore the allowable rail deformation is *1.5 cm*.

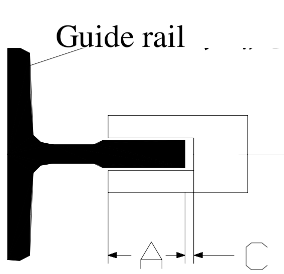


Fig. 3 Rail and Shoe Connection

Fig. 4 CW test frame

SHAKING TABLE TESTS

Full-scale shaking table tests were conducted at the NCREE in Taipei to understand the ultimate capacity and damage pattern of CW assemblies. A steel frame 3*m* × 4.5*m* × 9*m* (H) was designed to accommodate two full-scale CW in a test run as shown in Fig. 4. CW specimens were designed to enclose two different elevator systems, one for the 8-passenger and the other for the 15-passenger. The former has a CW assembly that weighs 1000 *kgf* (9800 N) and the latter 1500 *kgf* (14700 N). Current practices in Taiwan uses 5K rail for the former and 8K rail for the latter. The rail brackets are spaced in 2.5m as in most of the buildings would. Rail brackets usually are *L50×50×6* for the 5K rail and *L65×65×6* for the 8K rail. In Fig. 5, small black triangles represent the location of rail brackets and empty circles are for the location of guide shoes. The channel numbers for various locations on the rail are also shown in Fig. 5 for references.

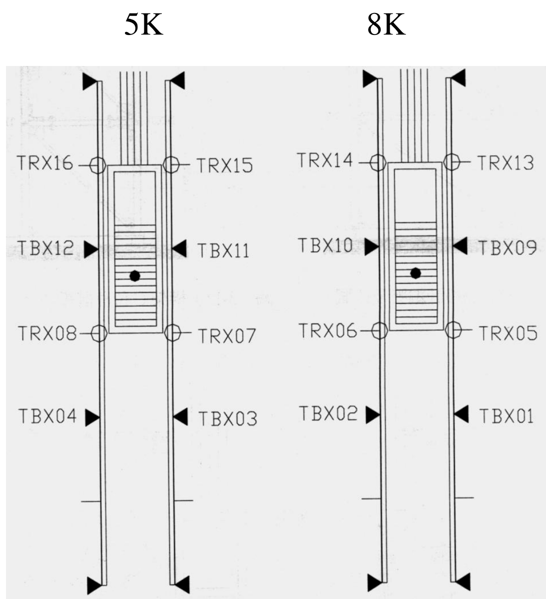


Fig. 5 Displacement Channels

Test records are artificially generated based on the measured 1999 Chi-Chi earthquake data taken from array time histories measured at various floors in 14 building as shown in Fig. 6.[8]

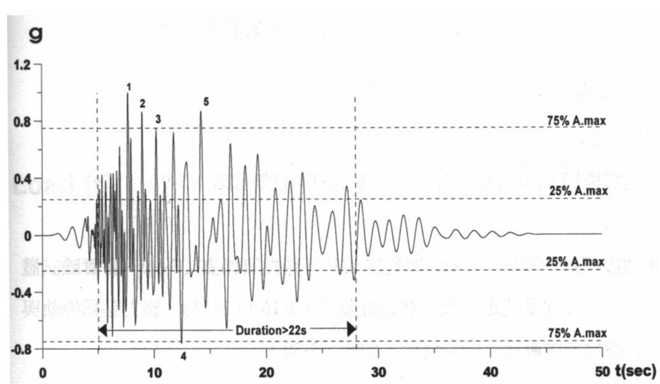


Fig. 6 Excitation time history

The response spectrum of these measured data was generated first and transformed into a strong motion time history which contains 5 peaks above 75% PA of the records and strong motion duration of 22 second above 25% of the PA. The PA of the records was incremented to apply on the test frame in the P_x direction until damage was observed on the two CW systems.

Standard Set (SS)

In this test set, current practices for the 8-passenger and 15-passenger CW system were tested. Test results are shown in Fig.7 and Fig. 8 for the 5K system, and Fig. 9 and Fig. 10 are for the 8K system.

From Fig. 7, it is observed that when the excitation PA reaches 0.586 G, the 5K rail deformation near the lower guide shoe has a measurement of 26.41 *mm* for TRX07 and 27.99 *mm* for TRX08, which means that both rail displacement are already above allowed value of 15 *mm* as described in the equation (5). Also observed is the bracket deformation (TBX12) increased drastically after PA=0.394G. After the final test, the rail bracket displacement is even larger than that of rails.

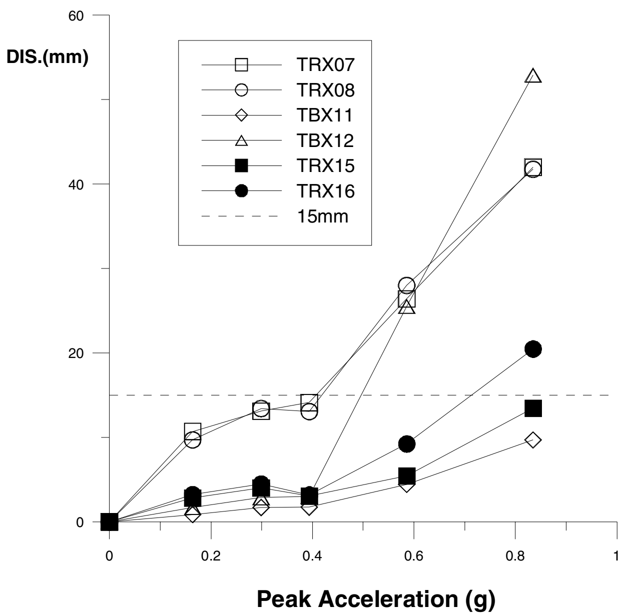


Fig.7 Largest displacement in the 5K test

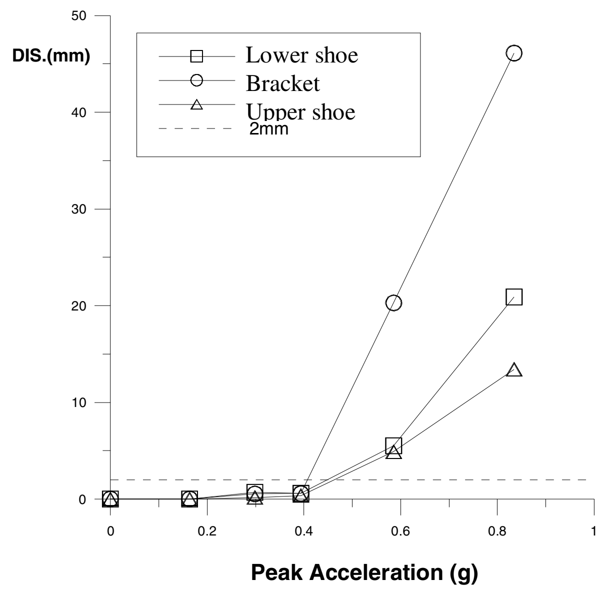
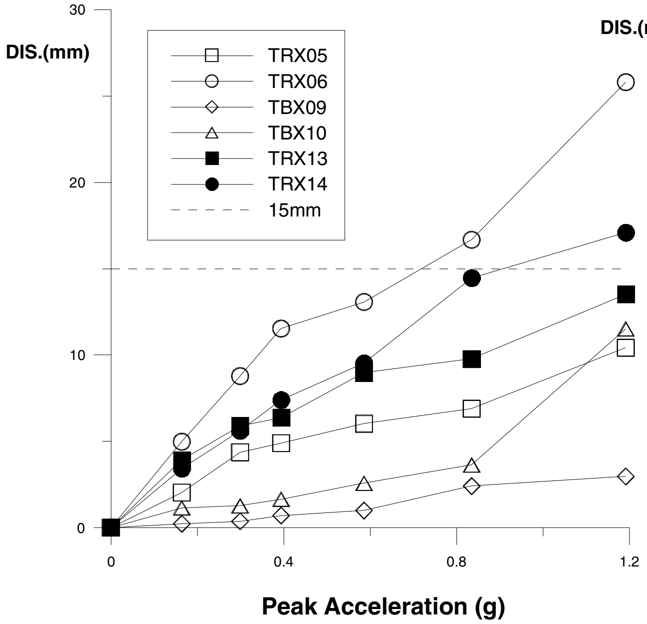


Fig. 8 Residual displacement from the 5K test

Fig. 8 indicates the residual displacement after each test. It is observed that after PA=0.586 G, rail gauge (RG) at both lower and upper guide shoe are over 5.5 *mm*, larger than the generally acceptable smooth running limit of RG=2 *mm*. Also observed is that after the last test, brackets has a final residual displacement of 46.1 *mm*, a lot larger than expected small deformation on the bracket.

Fig.9 and 10 records the largest and the residual displacement of the 8K systems. It is observed that when PA=0.835G, TRX06, representing rail displacement at the lower shoe, has a value of 16.66 *mm* that exceeds the limiting 15 *mm*. From Fig.10, the RG is observed to increase rapidly after PA=0.835G. After the final test, bracket deformation is also larger than the rail deformation reaching a value of 9.1 *mm*.



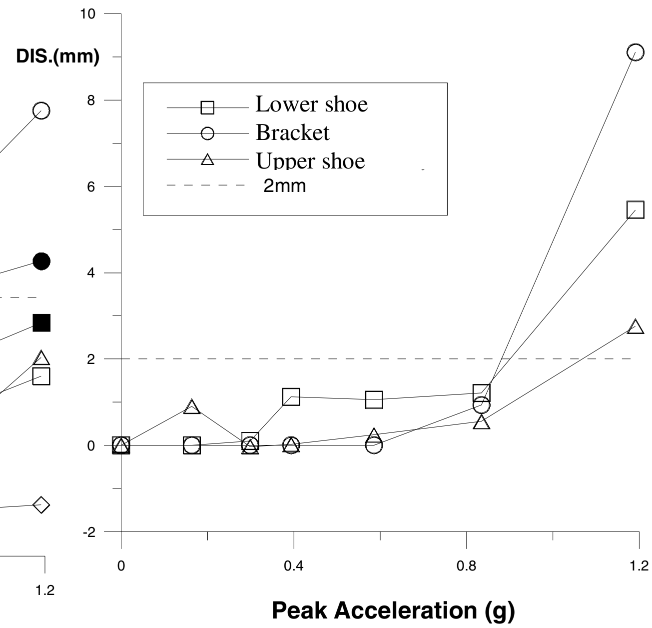


Fig.9 Largest displacement in the 8K test

Fig. 10 Residual displacement from the 8K test

Comparison Set (CS)

In this test, specimens are the same as in the Standard Set. The only difference is the excitation magnitude. Instead of incrementing excitation levels, a PA=0.8G is applied at one time to compare the effect of accumulated damage. Test data is shown in Table 1.

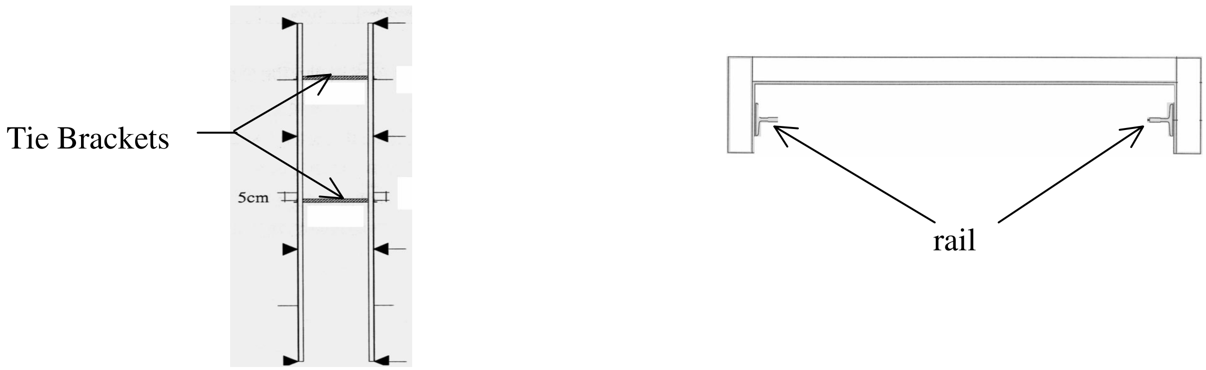
Table 1. Largest displacement of rails and brackets in the CS

LVDT #		TRX07	TRX08	TBX12	TRX15	TRX16
5K deformation (mm)	CS@0.80G	37.50	35.90	17.93	11.31	12.10
	SS@0.835G	41.98	41.74	52.89	11.95	17.11
(CS-SS)/SS		10%	14%	66%	5%	29%

It can be observed that test data in CS are generally smaller than those of SS. This indicated that current elevator practices may have accumulated damage from many small earthquakes.

Retrofitted Set (RS)

Two tie brackets of *L65×65×6* are installed on the 5K rails to retrofit the SS system and to observe its behavior under earthquake motions. The location of the brackets and its installation detail are shown in Fig. 11. Earthquake motions were input incrementally starting from 0.8G. The last excitation level ended with PA=1.3G when the shaking table capacity was exceeded. Until the last test, the maximum displacement of rails and brackets remain smaller than the 15 *mm* limit. This indicates that using tie brackets to rigidly connect both rails provides an effective measure for seismic retrofit. However, the residual displacement of the rail bracket at the last excitation caused a rail deformation up to 9 *mm.* This indicates that rail brackets need to be reinforced first if tie bracket retrofit is to be used.



(a) location of tie brackets **(b) details of tie bracket**

Fig. 11 5K rail with tie brackets

Other sets of testing are performed and described in Shen [7]. Detail descriptions are not discussed here due to page limit.

ENGINEERING DESIGN FOR CODE COMPLIANCE

If the single rail deformation limit of 15 *mm* is taken as the standard for acceptance or rejection of an elevator CW assembly, the derailment condition for a CW assembly between two rails will be the double of this value, i.e. 30 *mm*. Adopting this standard and comparing shaking table test result to the IBC2000 [9] for Taiwanese zoning division, Table 2 can be generated to demonstrate the K_H needed for designing elevator CW rail in Taiwan. In Table 2, different values in I_p (1.5, 1.25, and 1.0) corresponds to the latest Japanese code[10] for elevator design in designating different building class of S, A, and B.

Table 2. Design acceleration for CW rail in Taiwan

$0.4S_{DS}$	I_P	a_P	R_P	$\left[1+2\frac{h_x}{h_n}\right]$	K_H (G)
0.23G ZONE II	1 (B class)	2.5	2.5	3	0.69
	1.25 (A class)				0.86
	1.5 (S class)				1.04
0.33G ZONE I	1 (B class)	2.5	2.5	3	0.99
	1.25 (A class)				1.24
	1.5 (S class)				1.50

According to the test observation, it is believed that after rail brackets are retrofitted, Table 3 can be used to identify the strength of current elevator CW assemblies in different performance goal for Taiwan area according to the IBC2000 design formula. Symbols used in Table 3 a combination of zoning designation followed by building class.

Table 3. Current elevator CW strength for different building class

	Without Tie Bracket	With Tie Bracket
5K (8-Passenger Car)	Not Acceptable	II-S, II-A, II-B I-A, I-B
8K(15-Passenger Car)	II-S, II-A, II-B I-A, I-B	II-S, II-A, II-B I-S, I-A, I-B

CONCLUSIONS

This paper describes a series of shaking table tests on elevator CW assemblies for two types of elevators, 8-passenger and 15-passenger, commonly used in Taiwan. Comparing test results and adjusting the IBC2000 code to the Taiwanese Zoning practice, the following conclusions can be drawn:

1. Current design practice of guide rails neglects the deformation of rail brackets. It is found from the test results, that rail brackets do deform significantly. Therefore, a stiffer and stronger rail bracket design is needed for Taiwan's elevator design.
2. Shaking table result indicates that tie bracket can provide a stiffer rail system and resist larger earthquake force. However, the under-designed rail bracket compromises the full strength of tie bracket.

3. The current elevator CW assembly of using 5K rail without tie-brackets is insufficient for Taiwanese building code requirement. It can be improved by upgrading to 8K rails or installing tie brackets or both depending on the performance goal (building class) demand.

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