Damage and loss assessment for the basic earthquake insurance claim of residential RC buildings in Taiwan

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ABSTRACT A basic earthquake insurance policy associated with total loss coverage has been implemented in Taiwan to transfer risk caused by devastating earthquake. Acceptance of such an insurance claim depends on two criteria. One is that a building is identified as uninhabitable and requires rebuilding. The other is that the repair to replacement cost ratio of a building exceeds 50 per cent. Whether the first criterion is met or not depends on the building damage state, which can be determined through a damage rating system based on post-earthquake damage inspection on structural components and system. However, the second criterion has not been implemented for insurance adjuster without detail financial loss estimation by specialized engineers. In addition, there is no documented proof that these two criteria are consistent. This article aims to link post-earthquake damage of structural components to direct financial loss for RC residential buildings based on post-earthquake damage evidence. As a result, the second acceptance criterion can be implemented. The statistical analysis shows

that the two criteria are consistent on average. A new assessment procedure by incorporating criteria in terms of both damage and direct financial loss has been introduced. With this loss model, half loss coverage or partial loss coverage could be introduced into the basic earthquake insurance in this region.

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INTRODUCTION

Taiwan is located in an unstable tectonic zone between the Philippine Sea and Eurasian Plates. Seismic history is very rich in this area. Huge economic loss and human suffering often take place after a strong earthquake. Local scientific community has put a great deal of effort on earthquake forecast and warning, seismic design and retrofit technology, and disaster prevention and reduction system. However, even a well-constructed structure that meets the seismic design code may still be subjected to different levels of damage due to uncertainties in earthquake occurrence, design, construction and maintenance. In order to manage risks in an earthquake, earthquake insurance is often used to transfer financial impact (Kunreuther, 1996).

After the Chichi earthquake that caused enormous economic loss, Taiwan Residential Earthquake Insurance Program was created by the Ministry of Finance as part of the implementation of a comprehensive disaster prevention and risk management program. Within the insurance law, Taiwan Residential Earthquake Insurance Fund (TREIF) was established to facilitate a risk-sharing mechanism between insurance companies and the government to cover insured residential earthquake loss.

TREIF is responsible for the basic earthquake insurance of residential buildings. This insurance is participated through policy incidental to fire insurance. According to the current insurance policy (TREIF, 2007a), earthquake insurance with an upper limit of NT\$1 200 000 will be paid to cover the loss of an insured residential building if it is identified as in danger of collapse either visually or by structural damage, or if its repair cost exceeds 50 per cent the replacement cost of the building. Even the policy parties would like to know if these two policies are consistent. That is, whether the loss of a nearly collapsing building as identified by structural damage level corresponds to a repair to replacement cost ratio of more than 50 per cent.

According to current practice, after receiving earthquake damage claim application of the insurance target, a qualified adjuster of the insurance company will conduct an on-site inspection to identify the damage state of the building system and components. Although several loss estimation models (Whitman, 1973; ATC, 1985; Hwang *et al*, 1994; AIR, 2000; FEMA, 2003; Bal *et al*, 2008; Hill and Rossetto, 2008) exist to correlate building damage state to repair to replacement cost ratio, the building damage state is not quantified based on post-earthquake damage rating system and field inspection data. In order to fill in this gap, recorded damage data provided by individual engineers and from the rehabilitation program called the ‘Nest-Building’, which was initiated by the 921 Earthquake Relief Foundation, are used in this article. A new model is established to link inspected component damage level, building damage state and direct financial loss in terms of repair cost ratio. Damage of structural components are quantified by a set of damage factors and integrated as a building damage indicator. Building repair cost ratio and story repair cost ratio corresponding to various damage levels of reinforced concrete residential buildings are estimated. With these statistical data, the relationships of damage indicator to repair cost ratio can be built from regression analysis. With this model, a new

assessment procedure by incorporating criteria in terms of both damage and direct financial loss is introduced. The results serve as feedback to re-examine the current policy and criteria, and make further suggestions.

As reinforced concrete buildings make up about 77 per cent of all insured residential buildings according to statistics provided by TREIF, only the reinforced concrete buildings are considered in this article. In addition, after an earthquake, a building may be damaged by geotechnical deficiencies such as fault rupture, which may cause foundation damage, building differential settlement or soil liquefaction (Bird *et al*, 2006), landslide and damage to retaining wall, or by a tilting neighboring building without enough separation distance. Such damage mechanisms are outside the scope of this article.

EXISTING CLAIM ASSESSMENT BY DAMAGE-ORIENTED PROCEDURE

To process a claim for the basic earthquake insurance, a qualified insurance adjuster will conduct on-site post-earthquake inspection, damage evaluation and claim evaluation as illustrated in Figure 1.

On-site inspection

On-site inspections include identification of building collapse state, structural damage detection and identification of geotechnical deficiencies.

Building collapse state is detected visually. Targets of structural damage detection include measurement of building drift ratio or inter-story drift ratio, determination of foundation damage state, damage rating for structural columns, girders and walls of the most severely damaged story. As the foundation damage state is too difficult for a qualified insurance adjuster to determine, in practice, this is only used by licensed civil engineers when a reappraisal meeting is held. Therefore, damage assessment of structural components becomes very important.

Figure 1: Existing claim assessment flowchart.

Damage rating system for structural components

On the basis of the ‘building loss evaluation’ form (TREIF, 2007b), structural system damage state of an RC building can be defined according to the inspected damage levels of structural columns, girders and walls. The damage of each structural component is classified from damage levels I–V as defined in Table 1. As an example, girder damage levels are illustrated in Figure 2.

Building damage evaluation

Except collapse judgment by visual appearance, a building is classified as severely damaged and in danger of collapse when three of the first four of the following items are identified, or the last item and one of the first four items are identified at the same time.

1. Either building drift ratio or inter-story drift ratio exceeds 1/30.
2. More than 20 per cent of columns have foundation scour, or their foundations have shifted away from the upper structures for more than 5 cm.

Table 1: Damage-level descriptions for structural components

DL	Column	Girder	Wall
I	<ul style="list-style-type: none"> • slightly narrow crack 	<ul style="list-style-type: none"> • slightly narrow crack 	<ul style="list-style-type: none"> • slightly narrow crack (less than 0.3 mm horizontal crack width)
II	<ul style="list-style-type: none"> • clear crack (width within 0.3 mm) 	<ul style="list-style-type: none"> • clear crack (width within 0.3 mm) • plaster layer peeling 	<ul style="list-style-type: none"> • many horizontal crack extended to column (0.3–0.5 mm crack width)
III	<ul style="list-style-type: none"> • more than 0.3 mm crack width • spalling of concrete cover 	<ul style="list-style-type: none"> • more than 0.3 mm crack width • spalling of concrete cover • no broken stirrup • no buckled bars 	<ul style="list-style-type: none"> • inclined crack • no exposed reinforcing bars
IV	<ul style="list-style-type: none"> • exposed reinforcing bars without buckling • concrete core not crushed 	<ul style="list-style-type: none"> • extended spalling of concrete cover • partially broken stirrups • buckled bars 	<ul style="list-style-type: none"> • extended inclined crack • reinforcing bars exposed but not broken • spalling of concrete cover
V	<ul style="list-style-type: none"> • stirrups broken • reinforcing bars buckled • concrete core crushed • slab settlement • tilting 	<ul style="list-style-type: none"> • stirrups broken • reinforcing bars buckled • concrete core crushed • slab settlement • tilting 	<ul style="list-style-type: none"> • extended inclined crack • reinforcing bars buckled or broken • concrete core crushed • slab settlement • tilting

Figure 2: Example of damage levels for girders.

3. More than 10 per cent of columns reach damage level V, or the proportion of damaged columns, including both levels IV and V, exceeds 20 per cent.
4. More than 10 per cent of girders reach damage level V, or the proportion of damaged girders, including both levels IV and V, exceeds 20 per cent.
5. More than 10 per cent total length of structural walls reach damage level V, or the damaged length to total length ratio, including both levels IV and V damages, exceeds 20 per cent.

If none of the above five items is identified and no more than three of the following five items are identified, the building is classified as slightly damaged.

1. Either building drift ratio or inter-story drift ratio reaches $1/60$ – $1/30$.
2. Of all columns, 10–20 per cent have foundation scour, or their foundations have shifted away from the upper structures for more than 5 cm.
3. Columns with level IV or V damages are found, but the proportion, including both levels IV and V, is no more than 20 per cent.
4. Girders with level IV or V damages are found, but the proportion, including both levels IV and V, is no more than 20 per cent.
5. Structural walls with damage level IV or V are found but the ratio including both levels IV and V is no more than 20 per cent.

Claim evaluation

The basic earthquake insurance policy is associated with a claim of total loss or damage. Compensation for partial loss is not considered at present. According to the existing insurance policy (TREIF, 2007b), total loss of an insured RC residential building will be compensated if one of the following two conditions is found.

(1) The damaged building is uninhabitable, and rebuilding is required; (2) Residence is deemed uninhabitable without repair, and the corresponding repair cost exceeds 50 per cent of the replacement cost of the building. A building is classified as uninhabitable and rebuilding required if it has visually collapsed or if it is severely damaged and is in danger of collapse, as described above. The second condition is associated with direct financial loss, which is too difficult for a qualified insurance adjuster to estimate. Therefore, this criterion has not been used by the adjusters. The claim is rejected if the building is identified as slightly damaged according to the post-earthquake inspection. In the case where building damage is moderate, or in the case with geotechnical deficiency, TREIF will hold a reappraisal meeting and invite licensed civil engineers or specialists to review and perform detail assessment and loss estimation. If the repair to replacement cost ratio exceeds 50 per cent, the claim is accepted. Otherwise, the claim is rejected.

Therefore, the conclusion of claim evaluation may range from claim accepted, claim rejected and reappraisal meeting needed, and has been implemented in the 'Building Loss Evaluation Form for Residential Earthquake Insurance' (TREIF, 2007b) for the qualified insurance adjuster. Without detailed assessment by the licensed civil engineers, the entire assessment procedure carried out by an adjuster is damage-oriented. A loss model to link repair to replacement cost ratio, building damage state and structural component damage level is necessary to facilitate the current policy and to clarify if the damage-related policy is consistent with the financial loss-related policy.

CLAIM ASSESSMENT MODEL BASED ON DAMAGE AND LOSS

According to the above description, structural damage detection includes measurement of building drift ratio or inter-story drift ratio, determination of foundation damage state and damage rating of structural components. A new assessment model associated with these three aspects is proposed as follows.

In addition to visual determination, according to the state of the practice (TPCEA, 2006), a building with structural damage may be classified as collapsed if the building drift ratio exceeds 1/40. According to the state-of-the-art performance-based earthquake engineering (SEAOC, 1995; ATC, 1996; FEMA, 1997; SEAOC, 1999), inter-story drift ratio has been considered as the most suitable and simplest damage index. Because the ratio of inter-story drift ratio to building drift ratio is greater than 1 (Gupta and Krawinkler, 2000), a building with drift ratio or story drift ratio exceeds 1/30 can be conservatively regarded as collapsed. In fact, during post-earthquake inspection for emergency safety evaluation (CPA *et al*, 2005), a building drift ratio or an inter-story drift ratio of 1/30 is conservatively taken as one of the criteria to identify that the building is in danger of collapse. Considering that the drift ratio corresponds to the permanent displacement of a building, and taking into account of entire building tilting by geotechnical deficiency without structural component damage, building or story drift limits, together with structural component damage, is used as a screen criterion in the proposed claim assessment procedure.

As mentioned earlier in this article, the foundation damage state, such as foundation scour or shift, is too difficult for a qualified insurance adjuster to determine. However, such foundation damages are always associated with ground surface extrusion or cracking. In the proposed model, this item has been treated as one of the geotechnical deficiencies. In such cases, a reappraisal meeting will be held.

Existing loss estimation models mentioned earlier in this article also correlate building damage state with repair to replacement cost ratio. However, damage states in these references are qualified with descriptions such as no damage, negligible, slight, moderate and heavy damages and collapse. Such a rating system is not consistent with the post-earthquake damage rating system used in the claim assessment procedure. No connection has been made between the building loss ratio and the structural component damage level, particularly according to the local statistical data in engineering practice.

In this article, structural component damage is semi-quantified by a set of damage factors (DF) and integrated as a building damage factor (BDF) and a story damage factor (SDF). On the basis of the evidence of Chichi earthquake damage from a rehabilitation program, the ratio of repair cost to replacement cost, also known as building repair cost ratio ($BRCR$) and story repair cost ratio ($SRCR$), corresponds to various damage levels of RC residential buildings and has been estimated. With these statistical data, SDF – $SRCR$ relationship and BDF – $BRCR$ relationship can be built from regression analysis. With soft-story or weak-story failure mechanism in mind, only SDF – $SRCR$ relationship is used and presented in this article. A new claim assessment procedure is proposed based on this model.

Structural component damage factor

In Table 2, several sets of normalized damage factor (DF_I – DF_V) corresponding to damage levels I–V have been considered to semi-quantify component damage levels and are described as follows:

1. Case No. 1 adopts a linear function used in many semi-quantification methods such as the DER&U method (NFB, 1995) for bridge condition estimation.

Table 2: Component damage factors associated with different damage levels

DL	DF													
	Case No. 1	Case No. 2	Case No. 3	Case No. 4		Case No. 5-1		Case No. 5-2		Case No. 6	Case No. 7			
				Girder	Column or wall	Girder	Column	Wall	Girder	Column	Wall			
I	1/5	0	0.1	0	0	0.35	0.23	0.19	0.011	0.011	0.008	0	0.02	
II	2/5	0	0.2	0	0	0.44	0.44	0.44	0.103	0.118	0.144	0.43	0.05	
III	3/5	0	0.3	0	0.053	0.51	0.45	0.53	0.165	0.143	0.172	0.68	0.14	
IV	4/5	1/2	0.65	0.628	0.606	0.73	0.65	0.64	0.482	0.475	0.549	0.86	0.37	
V	I	I	I	I	I	I	I	I	I	I	I	I	I

Figure 3: DL-DF relationship of columns.

2. Case No. 2 neglects the first three damage levels and adopts a linear function for levels IV and V to simulate the ‘damaged column’ in Japanese claim acceptance criteria (TMN, 2007).
3. Case No. 3 takes the average of Cases No. 1 and 2.
4. Case No. 4 represents the value used by AIR (2000).
5. Cases No. 5-1 and 5-2 are two sets of values obtained from the statistical study of evidence for damage. In fact, various values for the same damage level can be obtained depending on the number of samples, component size, damage extent and unit price adopted by different engineers at different time. Only two sets of average values with significant difference are chosen.
6. Cases No. 6 and 7 adopt LOG and EXP functions, respectively, instead of the linear function in Case No.1.

For all cases, DF for a structural member without damage is 0.

As an example, the $DL-DF$ relationship of a column is illustrated in Figure 3. Cases 5-1 and 6 are close to Case No. 1, whereas Cases 4, 5-2 and 7 are close to Case No. 2. Case No. 3 is in the middle. Similar situation can be found for both columns and walls. Therefore, mostly Cases No. 1, 2 and 3 are considered. As will be discussed later, once BDF to the repair cost ratio is established based on any component damage factor scheme, the component damage factor scheme only affects the damage indicator of the sampling building. It will not affect its repair to replacement ratio. But finally, it will affect the regression function.

BDF and SDF

BDF can be estimated through equation (1) by assuming equal weights of structural columns, girders and walls. In equation (1), DF stands for damage factor. Subscripts C , G and W stand for columns, girders and walls, respectively. The three numerators represent the averaged damage factors for column type, girder type and wall type elements. By using the $DL-DF$ relationship, each numerator may be expressed as in equation (2) (using the first numerator as an example), where $n_{c,I}$, $n_{c,II}$, $n_{c,III}$, $n_{c,IV}$ and $n_{c,V}$ represent the number of columns with damage level I, II, III, IV and V, respectively. For structural walls, the corresponding number stands for the damaged length. Equation (1) is applicable to estimate SDF of a story j , SDF_j , by considering the components of that story only.

Figure 4: SDF-SRCR statistical data and regression functions.

In cases where structural component damages concentrate in one or several levels, BDF may be still small and not reflect the damage severity correctly. Therefore, SDF , which is the maximum SDF_j value of all stories, is chosen as the damage indicator. As such, both the proposed loss model that is based on the SDF - $SRCR$ relationship and the existing damage-oriented model focus on the most severely damaged storey. Conventional inspection that the adjusters are familiar with remains unchanged.

Equations (1) and (2) show that DL - DF relationship affects the building or storey damage indicators (BDF and SDF).

$$BDF = \frac{\sum_{i=1}^{n_c} DF_{C,i} + \sum_{i=1}^{n_b} DF_{G,i} + \sum_{i=1}^{n_w} DF_{W,i}}{n_c + n_b + n_w} \quad (1)$$

$$\frac{\sum_{i=1}^{n_c} DF_{C,i}}{n_c} = \frac{DF_I \times n_{C,I} + DF_{II} \times n_{C,II} + DF_{III} \times n_{C,III} + DF_{IV} \times n_{C,IV} + DF_V \times n_{C,V}}{n_c} \quad (2)$$

BRCR and SRCR

The standard building cost (TAA, 2006) includes costs of all items, except decoration cost, administrative expense, supervision fees, profits and taxes. In order to obtain a reasonable cost ratio that corresponds to the damage state of the selected building, same items must be considered to estimate both replacement cost and repair cost. In this article, replacement cost is estimated according to the construction cost reference table issued by

The Non-Life Insurance Association of The ROC (TNLIA-ROC, 2007). Repair is defined as restoring to its original state without upgrading. According to the engineering practice in Taiwan, the repair cost is estimated based on the standard unit cost of each item chosen for repair work (TPCEA, 2006). In order to consider uncertainties in human judgment and evaluation, unit price used in the rehabilitation project or provided in the reference (TPCEA, 2006) is adopted. As *BRCR* and *SRCR* are estimated for individual case based on the damage evidence, it is obvious that *DL-DF* relationship will not affect *BRCR* or *SRCR* of the sample buildings.

SDF–SRCR relationship

As mentioned earlier, only *SDF*–*SRCR* relationship is used in considering concentrated story failure. On the basis of the Chichi earthquake damage evidence as recorded in the ‘Nest-Building Rehabilitation Program’ and those provided by individual engineers, *SDF*–*SRCR* statistical data based on *DL-DF* relationship (using Case No. 3 as an example) are estimated in Figure 4. All data are associated with short- to medium-height buildings. No tall building has been included.

In Figure 4, *SDF*–*SRCR* statistical data have been categorized according to the existing damage and claim evaluation criteria as described earlier in this article. Data that meet the claim acceptance criteria correspond to buildings classified as severely damaged and in danger of collapse based on the existing assessment method. Data that barely meet the acceptance criteria correspond to buildings whose damage meets the minimum requirement for being classified as severely damaged and in danger of collapse. No compensation means the buildings are classified as slightly damaged. Data that are uncertain in their correspondence call for a reappraisal meeting according to the existing assessment procedure.

Several regression functions with good fitting degree (R^2) are shown in Figure 4. The quadratic function corresponds to the best fitting degree. However, it decreases after peaking at $SDF=0.41$ with $SRCR=81$ per cent. The logarithm function gives the second best fitting degree and shows similar trends reflecting the behavior of the data. But the function deviates significantly from the origin of the coordinate system. The modified exponential function passes through the origin of the coordinate system and asymptotically approaches to 1. However, it provides relatively poorer fitting degree. Considering that the total loss claim acceptance criterion associated with financial loss corresponds to a repair cost ratio of 50 per cent, accurate estimation of repair cost ratio much more than 50 per cent is not the main concern. The quadratic function can be used as claim criteria with $SRCR = -5.2171SDF^2 + 4.2401SDF - 0.051$ for $0.0123 \leq SDF \leq 0.4$. $SRCR$ is set as 0 per cent for $SDF < 0.0123$. For cases where $SDF > 0.4$, the claim is accepted as $SRCR$ exceeds 81 per cent. Owing to the fact that $SRCR=50$ per cent corresponds to $SDF=0.162$, either $SDF > 0.162$ or $SRCR > 50$ per cent can be used as the acceptance criterion. Because the quadratic function also deviates from the origin of the coordinate system and the $SRCR$ of buildings with damage that barely meet the current acceptance criteria varies from 28.73 per cent to 75.14 per cent, for cases where $SRCR$ falls between 40 per cent and 50 per cent, a reappraisal meeting is recommended.

As *DL-DF* relationship affects *SDF*, *SDF*–*SRCR* statistical data are dependent of *DL-DF* functions. By using the quadratic function in regression analysis, influence of *DL-DF* relationship to *SDF*–*SRCR* regression function is illustrated in Figure 5. Again, the result of Case No. 3 lies between Case No. 1 and Case No. 2. Good fitting degree can be found for Cases No. 2 and 3. Case No. 1 is not considered because of the relatively poor fitting degree. Case No. 3 may overestimate building loss especially when all

Figure 5: Influence of DL-DF to SDF-SRCR regression function.

Figure 6: SDF-SRCR regression function by using DL-DF relationship of Case No. 2.

structural components are slightly damaged (damage level III). To overcome this problem, SDF-SRCR regression function (Figure 6) obtained by using DL-DF relationship of Case No. 2 can be used. Again, $SRCR = -6.4978SDF^2 + 4.3709SDF + 0.0795$ for $SDF \leq 0.336$. For cases where $SDF > 0.336$, the claim is accepted as SRCR exceeds 81 per cent. Owing to the fact that $SRCR = 50$ per cent corresponds to $SDF = 0.116$, either $SDF > 0.116$ or $SRCR > 50$ per cent can be used as the acceptance criterion. A reappraisal meeting is recommended for SRCR between 40 per cent and 50 per cent.

CONSISTENCY OF THE TWO ACCEPTANCE CRITERIA

From Figures 4 and 6, we can see if the current two acceptance criteria are consistent. That is, whether the criterion based on the proportion of severely damaged components matches with the criterion in terms of repair cost ratio or not. For buildings with damage that barely meets the current acceptance criteria, *SRCR* varies from 28.73 per cent to 75.14 per cent. A claim with *SRCR* value less than 50 per cent may be accepted based on the existing damage-oriented assessment procedure. In view of this, the second acceptance criterion associated with financial loss is relatively stringent. However, the mean and medium values are around 49 per cent and 51.9 per cent, respectively. From this perspective, both criteria may be considered as consistent.

HALF LOSS AND PARTIAL LOSS COVERAGE

With the proposed loss model, half loss or partial loss coverage could be introduced into the basic earthquake insurance in Taiwan in the future. For example, half loss coverage means half of the amount insured can be paid for $20\text{ per cent} \leq \text{SRCR} \leq 50\text{ per cent}$, and it is limited to NT\$600 000. On the other hand, partial loss coverage can be applied for $20\text{ per cent} \leq \text{SRCR} \leq 50\text{ per cent}$ with proportional reduction in payments.

THE PROPOSED CLAIM ASSESSMENT WORKFLOW

On the basis of the proposed assessment model that uses *DL-DF* relationship in Case No. 2 as an example, a new total loss assessment procedure based on both post-earthquake on-site inspection of structural damage and direct financial loss has been presented in Figure 7 for a qualified insurance adjuster. By conducting a conventional post-earthquake

Figure 7: Claim assessment procedure based on structural damage and loss.

on-site inspection, a qualified adjuster can make a claim evaluation based on direct loss estimation according to the proposed loss estimation model.

CONCLUSIONS AND RECOMMENDATIONS

The existing damage-oriented assessment procedure and acceptance criteria for a basic earthquake insurance claim have been examined. A new assessment procedure is proposed based on both damage and loss evaluation. A loss estimation model has been presented based on certain post-earthquake damage evidence. This model links structural component damage levels DL with the maximum story damage factor SDF and the corresponding story repair cost ratio $SRCR$. According to a comparison study of several DL – DF relationships, Case No. 3 with DF factors of 0.1, 0.2, 0.3, 0.65 and 1, and Case No. 2 with DF factors of 0, 0, 0, 0.5, 1 for component damage levels I, II, III, IV and V, respectively, can be used.

The relationship between SDF and $SRCR$ has been chosen to build the loss estimation model because building damage factor BDF and its associated repair cost ratio $BRCR$ do not indicate the real damage state correctly if damages are concentrated in one or several stories as in the case of a soft-story or a weak-story failure mechanism.

On the basis of the statistical data, by using the DL – DF relationship in Case No. 3, a quadratic regression function $SRCR = -5.2171 \times SDF^2 + 4.2401 \times SDF - 0.051$ is used for $0.0123 \leq SDF \leq 0.4$. $SRCR$ is set as 0 per cent for $SDF < 0.0123$. For cases where $SDF > 0.4$, the claim is accepted as $SRCR$ exceeds 81 per cent. Owing to the fact that $SRCR = 50$ per cent corresponds to $SDF = 0.162$, either $SDF > 0.162$ or $SRCR > 50$ per cent can be used as the acceptance criterion. Because the quadratic function also deviates slightly from the origin of the coordinate system, and the $SRCR$ of buildings with damage that barely meets the current acceptance criteria varies from 28.73 per cent to 75.14 per cent. For cases where $SRCR$ falls between 40 per cent and 50 per cent, a reappraisal meeting is recommended.

The regression function $SRCR = -5.2171 \times SDF^2 + 4.2401 \times SDF - 0.051$ by using DL – DF relationship in Case No. 3 may overestimate building loss particularly if all structural components are slightly damaged (without exceeding damage level III). To overcome this problem, SDF – $SRCR$ regression function obtained by using DL – DF relationship of Case No. 2 may be used. Again, $SRCR = -6.4978 \times SDF^2 + 4.3709 \times SDF + 0.0795$ for $SDF \leq 0.336$. For cases where $SDF > 0.336$, the claim is accepted since $SRCR$ exceeds 81 per cent. Either $SDF > 0.116$ or $SRCR > 50$ per cent may be used as the acceptance criterion. A reappraisal meeting is recommended for $SRCR$ between 40 per cent and 50 per cent.

For buildings with damage that barely meets the current acceptance criteria, $SRCR$ varies from 28.73 per cent to 75.14 per cent. A claim with $SRCR$ value less than 50 per cent may be accepted based on the existing damage-oriented assessment procedure. From this point of view, the second acceptance criterion associated with financial loss is relatively stringent. However, the mean and medium values are about 49 per cent and 51.9 per cent, respectively. From this point of view, both criteria may be considered consistent.

Using the proposed loss model, half loss or partial loss coverage could be introduced as well. For example, half loss coverage means half of the amount insured can be paid for $20 \text{ per cent} \leq SRCR \leq 50 \text{ per cent}$, and it is limited to NT\$600 000. Alternatively, partial loss coverage can be applied for $20 \text{ per cent} \leq SRCR \leq 50 \text{ per cent}$ with proportional reduction in payments.

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REFERENCES

- Applied Insurance Research (AIR). (2000) The Advanced Component Method (ACM™). Applied Insurance Research, Boston, MA, http://www.air-worldwide.com/_public/NewsData/000135/ACM.pdf.
- Applied Technology Council (ATC). (1985) Earthquake Damage Evaluation Data for California. California: Redwood City. Report No. ATC-13.
- Applied Technology Council (ATC). (1996) Seismic Evaluation and Retrofit of Concrete Buildings. California: Redwood City. Report No. ATC-40, Vol. 1.
- Bal, I.E., Crowley, H., Pinho, R. and Gulay, F.G. (2008) Detailed assessment of structural characteristics of Turkish RC building stock for loss assessment models. *Soil Dynamics and Earthquake Engineering* 28(10/11): 914–932.
- Bird, J.F., Bommer, J.J., Crowley, H. and Pinho, R. (2006) Modeling liquefaction-induced building damage in earthquake loss estimation. *Soil Dynamics and Earthquake Engineering* 26: 15–30.
- Construction and Planning Agency (CPA). (2005) *Post-Earthquake Damage Evaluation Guideline*. Construction and Planning Agency, Ministry of Interior (in Chinese).
- Federal Emergency Management Agency (FEMA). (1997) Second Ballot Version, NEHRP Guidelines for Seismic Rehabilitation of Buildings. Washington DC: BSSC. Report No. FEMA-273.
- Federal Emergency Management Agency (FEMA). (2003) *Multi-hazard Loss Estimation Methodology, Earthquake Model HAZUS-MHMR1, Advanced Engineering Building Module, Technical and User's Manual*. Washington DC: Federal Emergency Management Agency.
- Gupta, A. and Krawinkler, H. (2000) Estimation of seismic drift demands for frame structures. *Earthquake Engineering and Structural Dynamics* 29: 1287–1305.
- Hill, M.P. and Rossetto, T. (2008) Do existing damage scales meet the needs of seismic loss estimation? *The 14th World Conference on Earthquake Engineering*; 12–17 October, Beijing, China.
- Hwang, H.M., Xu, M. and Huo, J.-R. (1994) *Estimation of Seismic Damage and Repair Cost of the University of Memphis Buildings*. Memphis, TN: The University of Memphis.
- Kunreuther, H. (1996) Mitigating disaster losses through insurance. *Journal of Risk and Uncertainty* 12: 171–186.
- National Freeway Bureau (NFB). (1995) *General Inspection Manual for Highway Bridges*. Taiwan: National Freeway Bureau, MOTC (in Chinese).
- Structural Engineering Association of California (SEAOC). (1995) *Conceptual Framework for Performance Based Seismic Engineering of Buildings, Vision 2000*. Sacramento, CA: Structural Engineering Association of California.
- Structural Engineers Association of California (SEAOC). (1999) *Recommended Lateral Force Requirements and commentary*. Sacramento, CA: Structural Engineers Association of California.
- Taipei Professional Civil Engineers Association (TPCEA). (2006) *Guideline for Building Damage Evaluation Caused by Nearby Construction in Taipei*. Taipei, Taiwan: Taipei Professional Civil Engineers Association. Peer Reviewed by Public Works Department of Taipei City Government (in Chinese).
- Taiwan Architects Association (TAA). (2006) *Reference Table of the Total Construction Cost for Buildings*. Taiwan: Taiwan Architects Association (in Chinese).
- Taiwan Residential Earthquake Insurance Fund (TREIF). (2007a) *Manual of Standard Claim Procedure for Residential Earthquake Insurance*. Taipei, Taiwan: Taiwan Residential Earthquake Insurance Fund (in Chinese).
- Taiwan Residential Earthquake Insurance Fund (TREIF). (2007b) *Building Loss Estimation Form for Residential Earthquake Insurance*. Taipei, Taiwan: Taiwan Residential Earthquake Insurance Fund (in Chinese).
- The Non-Life Insurance Association of The ROC (TNLIA-ROC). (2007) *Construction Cost Reference Table for Residential Buildings in Taiwan*. Taipei, Taiwan: The Non-Life Insurance Association of The ROC (in Chinese).
- Tokyo Marine Nichido (TMN). (2007) *Japan earthquake Insurance*. Tokyo, Japan: Tokio Marine & Nichido Fire Insurance Co. Ltd. (in Japanese).
- Whitman, R.V. (1973) *Damage Probability Matrices for Prototype Buildings*. Cambridge, MA: Department of Civil Engineering, Massachusetts Institute of Technology. Research Report R73–57.