Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 67 (1993)

Artikel: Strength evaluation of existing masonry structures
Autor: Zhou, Xinggang
DOI: https://doi.org/10.5169/seals-51370

Nutzungsbedingungen
Die ETH-Bibliothek ist die Anbieterin der digitalisierten Zeitschriften auf E-Periodica. Sie besitzt keine Urheberrechte an den Zeitschriften und ist nicht verantwortlich für deren Inhalte. Die Rechte liegen in der Regel bei den Herausgebern beziehungsweise den externen Rechteinhabern. Das Veröffentlichen von Bildern in Print- und Online-Publikationen sowie auf Social Media-Kanälen oder Webseiten ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Mehr erfahren

Conditions d'utilisation
L'ETH Library est le fournisseur des revues numérisées. Elle ne détient aucun droit d'auteur sur les revues et n'est pas responsable de leur contenu. En règle générale, les droits sont détenus par les éditeurs ou les détenteurs de droits externes. La reproduction d'images dans des publications imprimées ou en ligne ainsi que sur des canaux de médias sociaux ou des sites web n'est autorisée qu'avec l'accord préalable des détenteurs des droits. En savoir plus

Terms of use
The ETH Library is the provider of the digitised journals. It does not own any copyrights to the journals and is not responsible for their content. The rights usually lie with the publishers or the external rights holders. Publishing images in print and online publications, as well as on social media channels or websites, is only permitted with the prior consent of the rights holders. Find out more

Download PDF: 05.09.2025

ETH-Bibliothek Zürich, E-Periodica, https://www.e-periodica.ch

Strength Evaluation of Existing Masonry Structures
Evaluation de la résistance de constructions en brique
Festigkeitsermittlung für bestehende Mauerwerksbauten

Xinggang ZHOU
Research Assist.
Yantai University
Yantai, China

Zhou Xinggang, born in 1963, received his engineering master's degree from Tsinghua University, China in 1989. Now he is a research assistant in Civil Engineering.

SUMMARY
According to experimental data and theoretical analysis, the relationship between strength and rigidity, rigidity deterioration, accumulated deformation energy in earthquake damage of masonry structures are studied. Methods are suggested that show how to evaluate the strength of masonry structures in serviceability state, and how to predict and evaluate the damage degree of masonry structures by earthquakes.

RÉSUMÉ
Sur la base de données d'essai et d'analyses théoriques, l'article étudie la relation entre la résistance de constructions en brique et la rigidité, la détérioration de rigidité, l'énergie de déformation accumulée lors de séismes. Des méthodes sont proposées pour l'évaluation de la résistance et de l'aptitude au service de constructions en briques, ainsi que pour l'évaluation de dommages possibles lors de séismes.

ZUSAMMENFASSUNG
Anhand experimenteller Ergebnisse und theoretischer Überlegungen, wird der Zusammenhang zwischen Festigkeit und Steifigkeit sowie des Steifigkeitsabfalls mit der kumulierten Verformungsenergie bei Erdbebenschäden an Mauerwerksbauten studiert. Es werden Verfahren vorgeschlagen, wie aus dem Gebrauchsverhalten von Mauerwerk auf seine Robustheit geschlossen und wie der Schädigungsgrad im Erdbebenfall vorhergesagt und evaluiert werden kann.

1. INTRODUCTION

As for existing masonry structures, it is known that many of them are in illness state in their serviceability life time, slightly or seriously. In fact, suffering various unfavourable factors in construction and application, such as dispersity of masonry material, temperature cracks etc. , masonry structures are in insufficient strength or strength deterioration state which is one of illness state concerned seriously. But the problem how to precisely examine the real serviceability state of masonry structures have not been solved for a long time. In this paper, mothod solving this problem was investigated, and the mothod developed from experimental information and theoretical analysis.

2. STRENGTH AND RIGIDITY

2.1 Compressive strength and rigidity

Compressive stress—strain curve of masonry envalope can be expressed[1][2]:

$$\sigma = f_m(1 - e^{-\alpha f_m^{1/2}\varepsilon}) \qquad (2-1)$$

where, σ and ε are compressive stress and strain respectively. f_m is the compressive strength of masonry envalope, α is a coefficient. Therefore, elastic modulus of masonry envalope can be obtained:

$$E = \frac{d\sigma}{d\varepsilon}\Big|_{\varepsilon=0} = \alpha f_m^{3/2} \qquad (2-2)$$

Based on experimental information[1], the statistical value of α is 370. As we know, the (lateral) rigidity K is equal to the ratio of lateral load to displacement:

$$K = \frac{1}{\delta} = \frac{1}{\frac{h^3}{12EI} + \frac{h\xi}{GA}} = \frac{1}{\frac{h^3}{Etb^3} + \frac{1.2h}{0.3Etb}} = \frac{Et}{(\frac{h}{b})^3 + 4(\frac{h}{b})} \qquad (2-3)$$

Substituting equation (2 — 2) into formula (2 — 3), the ralation bettween rigidity and compressive strength can be got:

$$K = \frac{\alpha f_m^{3/2} t}{(\frac{h}{b})[(\frac{h}{b})^2 + 4]} \qquad (2-4)$$

in which, t, h and b are the thickness, height and width of masonry wall respectively.

2.2 Shear strength and rigidity

Researching the hysteresis characteristic of masonry wall [1] [2] [3], the statistical skeleton curve of hysteresis loops are shown in Figure 1, it is indicated that in the initial stage the load—displacement relationship is linear and after cracking the displacement increases significantly with appeared and developed cross cracks. Defined P_u as the ultimate load, $\triangle u$ as the displacement in regard to p_u, and σ_c is the normal stress of masonry wall. The skeleton curve can be expressed as follow:

$$(1)\ P/P_u = 2.6\frac{\triangle}{\triangle u} \qquad (0 < P/P_u \leqslant 0.78, 0 < \frac{\triangle}{\triangle u} \leqslant 0.3) \quad (2-5)$$

$$(2)\ P/P_u = 0.69 + 0.31\frac{\triangle}{\triangle u} \qquad (0.78 < P/P_u \leqslant 1; 0.3 < \frac{\triangle}{\triangle u} \leqslant 1) \qquad (2-6)$$

$$(3)\ P/P_u = 1 + 0.44(1 - 0.085\sigma_c) - 0.44(1 - 0.085\sigma_c)\frac{\triangle}{\triangle u} \qquad (2-7)$$

$$(P/P_u < 1; 1 \leqslant \frac{\triangle}{\triangle u} \leqslant 0.3)$$

$$(4)\ P/P_u = 0.55 + 0.04\sigma_c \qquad (2-8)$$

From formula(2—5), the rigidify K can be written as follow also:

$$K = \frac{P}{\triangle} = 2.6\frac{P_u}{\triangle u} = 2.6\frac{f_v tb}{\triangle u} \qquad (2-9)$$

where, f_v is the shear strength of masonry wall. According statistical analysis, the ralationship bettween f_v and $\triangle u$ is:

$$\triangle u = (3 + 4.5f_v)^{1/2}/(0.45 + 0.05\sigma_c) \qquad (2-10)$$

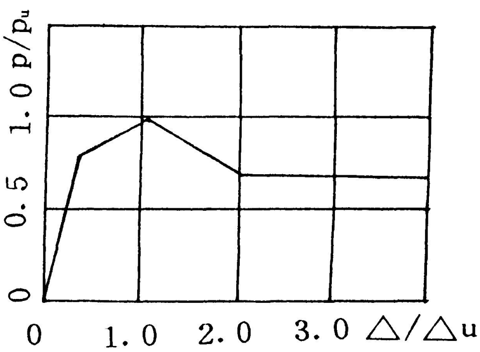

Fig. 1 Skeleton curve of masonry wall

Thus,

$$K = \frac{(1.17 + 0.13\sigma_c)f_v tb}{(3 + 4.5f_v)^{1/2}} \qquad (2-11)$$

Equation (2 — 11) illustrates the ralationship bettween the rigidity K and the shear strength f_v.

2.3 Rigidity deterioration

Looking Fig. 1 again, it can be found that as increasing of displacement the stiffness of masonry wall decrease obviously. The stiffness K′ at any displacement many be calculated from the following empirical formula:

$$K' = 0.0017(\triangle/H)^{-0.91}K \qquad (\triangle/H > 1/1000) \qquad (2-12)$$

In other word, formula(2—12)show the deteriration of rigidity as increasing of displacement △ under later load.

3. ACCUMMLATED DEFORMATION ENERGY AND DAMAGE INDEX

3.1 Input energy of perunit mass

The problem related to the strength and stiffness of masonry wall in serviceability state are discussed above. In order to predict the damage degree of masonry structure, accumulated deformation energy should be stuided, because any damage by earthquake is the result of accumulated deformation in vabration process Assume that w is the accumulated deformation energy[4,5]. As for one—freedom system, in general,

$$W = \frac{1}{2}m\dot{X}^2_{emax} \qquad (3-1)$$

where, $\dot{X}_{emax}$ is the maximum value of elastic vabration velocity of system, and,

$$\dot{X}_{emax} = \dot{y}_{max}/2^{1/2} \qquad (3-2)$$

$\dot{y}_{max}$ is the maxiumum velocity of earth's surface vabration. Substitute formula (3—2) into formula (3—1), then,

$$W = \frac{1}{4}m\dot{y}^2_{max} = mE_0 \qquad (3-4)$$

E_0 can be defined as the input energy of perunit mass. From statitical analysis, E_0 can be formulated as follow:

$$E_0 = \frac{1}{4}\dot{y}^2_{max} = exp(1.385I - 6.39) \qquad (3-5)$$

Where, I is the earthquake intensity.

3.2 Damage index of masonry structure

The vabration equilibrium equation of ith storey for multistorey masonry structures can be expressed (damp is neglected):

$$m_n(\sum_{j=1}^{n}\ddot{x}_j + \ddot{y}) + m_{n-1}(\sum_{j=1}^{n-1}\ddot{x}_j + \ddot{y}) + \cdots\cdots + m_i(\sum_{j=1}^{i}\ddot{x}_j + \ddot{y}) = f_i(x_i) \qquad (3-6)$$

Multiplying the equation by $\dot{x}_i dt = dx_i$, and integralling the equation in the whole vabration time, thus

$$\int(\sum_{k=1}^{n}m_k\sum_{j=1}^{k}\ddot{x}_j)dx_i + \int\dot{x}_i\sum_{k=i}^{n}m_k\ddot{y}dt = \int f_i(x_i)\dot{x}_i dt \qquad (3-7)$$

It is noted that:

$$\int\ddot{x}_j dx_i = \int\ddot{x}_i dx_j = \int\dot{x}_j d\dot{x}_i = \int\dot{x}_i d\dot{x}_j = 0$$

$$\int\ddot{y}\dot{x}_1 dt \doteq \int\dot{x}_1 d\dot{x}_1$$

$$x_i = h_i x_1/h_1$$

therefore,

$$w_i = \int f_i(x_i)dx_i = \sum_{k=i}^{n}m_k\int\ddot{y}dx_i = \sum_{k=i}^{n}m_k\int\frac{h_i}{h_1}\dot{x}_1 d\dot{x}_i = \sum_{k=i}^{n}m_k\frac{h_i}{h_1}E_0 \qquad (3-8)$$

h_i, h is the height of storey.

Assume that η_p and η are the ratio of ultimate deformation energy to elastic deformation energy and the ratio of deformation energy to elastic deformation energy respectively. According to experimental date, η_p is about 12 refer to masonry structures. η_i can be wrote as follow:

$$\eta_i = W_i/W_{iy} = 2\sum_{k=i}^{n} m_k \frac{h_i}{h_1} E_0/P_{cr}\triangle cr = 2K_r \sum_{k=i}^{n} m_k \frac{h_i}{h_1} E_0/(\gamma f_v tb)^2 \qquad (3-9)$$

γ is a statitical factor which is equal to 0. 78. Let β express the damage index of masonry structures by earthquake, then,

$$\beta = \frac{W - W_y}{W_f - W_y} = \frac{\eta - 1}{\eta_f - 1} \qquad (3-10)$$

From experimental and earthquake damage information[2, 3, 6], it can be defined that:

$\beta \geqslant 1.0$	*partly collapse*
$0.90 \leqslant \beta < 1.0$	*serious damage*
$0.50 \leqslant \beta < 0.90$	*moderate damage*
$0.15 \leqslant \beta < 0.50$	*slight damage*
$0 \leqslant \beta < 0.15$	*intact state*

4. APPLICATION

4. 1 Application

Up to now, we discussed the strength, rigidity and accumulated deformation energy. In this section, we will discuss how to evalute the strength of masonry structures in service. Serviceability state and how to predict the damage of masonry structure by earthquake. As we know that structure's natrual frequency and mode of vabration can be measured and analyzed from ambient vabration. So the rigidity of structures can be identified using the date of natrual frequency, mode of vabration and equibibrium equation of vabration. Since the rigidity can be indentified, substituting the rigidity into formulae (2—4)and(2—11). Using formulae (2—1)and(2—3), the compressive and shear strength of masonry structures can be evaluted. On the basis of these results, it can be found that which storey is the weak part in serviceabilty state or under earthquake circumstance. Applying (3—9)and(3—10), it can be pridicted that which degree of damage will be caused under grant earthquake intensity.

4. 2 Example

A multistorey masonry structure. Seven storey, the height of storey is 2800mm. it's plane figure refering to Fig2. The thickness of outer horizatal wall is 490mm, inter horizatal wall are 370mm(the first floor) and 240mm (from the second to the seventh). The thickness of outer transerve wall is 370mm. The results of measured date from ambient vabration are show in table 1. Using the date of table 1 and the method discussed above. The distribution of rigidity, strength and damage index under seven degree of earthquake intersity etc are caculated and shown in table 2.

Table 1. The results of ambient vabration

Floor	weight(kg)	Ai(mm)	K_i(KN/m)
1	6.928×10^5	0.019	8.75×10^6
2	6.566×10^5	0.038	8.53×10^6
3	6.566×10^5	0.061	6.74×10^6
4	6.566×10^5	0.16	1.42×10^6
5	6.566×10^5	0.18	55.43×10^6
6	6.566×10^5	0.20	33.50×10^6
7	4.156×10^5	0.26	1.49×10^6
note	frenquence $f_1=2.832$HZ		

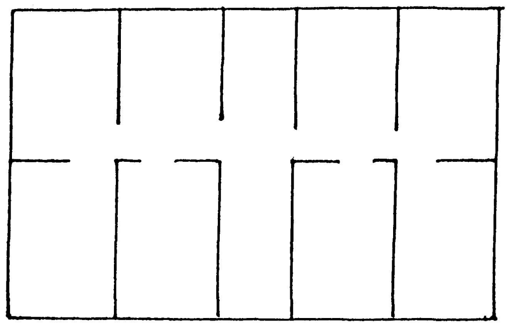

Fig. 2 Plane figure of example

Table 2 The results of evalution

Floor	K_i(KN/m)	Compressive strength(MP_a)	shear strength(MP_a)	compressive stress(MP_a)	earthquake shear stress	Damage index
1	8.75×10^6	2.80	0.47	0.47	0.15	0
2	8.53×10^6	3.62	0.599	0.55	0.29	0.44
3	6.74×10^6	3.10	0.440	0.46	0.26	0.13
4	1.42×10^6	1.10	0.076	0.36	0.23	7.10
5	5.43×10^6	2.68	0.332	0.27	0.18	0.20
6	3.50×10^6	2.00	0.200	0.19	0.122	0.30
7	1.44×10^6	1.13	0.092	0.09	0.05	0.26

note: 1. earthquake intensity is seven degree.
2. earthquake shear stress caculated by equivalent base shear method.

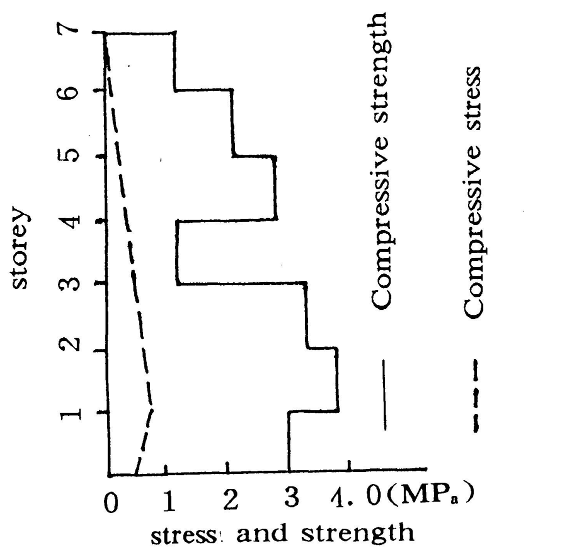

Fig. 3 Distribution of compressive strength and stress

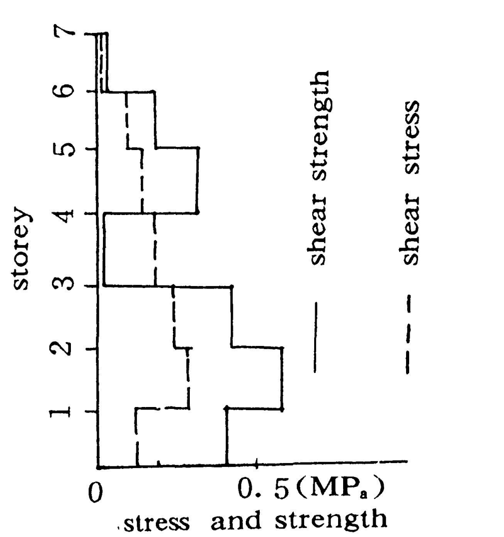

Fig. 4 Distribution of shear strength and stress

6. CONCLUSION AND DISCUSSION

① Above, the strength, the rigidity, the deformation energy and the damage index of masonry structure are studied. Ralationship bettween them are given also.

② Using the ralationship and date from ambient vabration, the serviceiability state of existing masonry structures can be asserted, and the damage index by earthquake can be predict also.

③ Based on experimental statisfical information and structural dynamic analysis. The method reflect every aspect involved in masonry structure and suggest a way to examine the existing masonry structure comprehensively.

④ Example show that the compressive strength, the shear strength and the damage index evaluted by the mathod are in good agreement.

⑤ Examples show that the mathod are feasible. The assertment results of existing masonry structure are reliability.

⑥ Further investigation should be carried and make the mothod more perfecter.

REFERENCES

1. YiLiang Q. The paper slection of masonry structures, Huonan university publish house, 1989.

2. Jing qin, X. Some problem about seismic Resistance of Brick Masonry walls. The proceding of Seismic Risistance Vol2. 1986.

3. Jumin S, Xinggong Z, Shiping F, Seismic Behavior of Reinforced Brick Masonry Cavity walls, IABSE SYMPOSIUM BRUSSELS 1990,

4. G. W. Houser, Limit Design of Structures to Risist Earthquakes, Pros, ist. W, c. E. E. Berkeleg 1986.

5. Haodong L, The evalution of Brick Masonry Structures after Earthquakes, The proceeding of Seismic Resistance vol 1. 1986

6. Yucheng, Y. The Analysis of Damage to Multistorey Brick Buildings During the Tangshang Earthquake, Congress Earthquake Protection of Construction in Sersmic Area Ramania, 1978. 11

7. Bao zhiwen. etal. Ambient Vibration Survey of Some High Building in Hongkong. Tsinghua Publish House, 1985