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Code for Design of Strengthening Masonry Structures

砌体结构加固设计规范

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Announcement of Ministry of Housing and Urban-Rural Development of the People's Republic of China

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Announcement on Publishing the National Standard *Code for Design of Strengthening Masonry Structures*

Code for Design of Strengthening Masonry Structures has been approved as a national standard with a serial number of GB 50702 - 2011 and shall be implemented from August 1, 2012. Thereinto, Articles 3.1.9, 4.2.3, 4.3.6, 4.4.3, 4.5.2, 4.5.3, 4.5.5, 4.6.1, 4.6.2, 4.6.3, 4.7.5, 4.7.7, 9.1.7 and 10.1.4 are compulsory provisions and must be enforced strictly.

Authorized by the Standard Rating Research Institute of Ministry of Housing and Urban-Rural Development of the People's Republic of China, this Code is published by China Architecture & Building Press.

Ministry of Housing and Urban-Rural Development of the People's Republic of China

July 26, 2011

Foreword

This Code was formulated by Sichuan Institute of Building Research jointly with the organizations concerned according to the requirements of *Development and Revision Plan of Engineering Construction Standards in* 1989 issued by the former Ministry of Construction.

During the process of formulating this Code, the drafting group conducts monographic study on various structure strengthening methods, carried out extensive investigations and analysis and proving tests on key projects, summarized design experience in the strengthening of masonry structures in the past two decades and carried out comparative analysis of and referred to the foreign advanced standards and codes, based on which, it extensively asked for opinions of the organizations concerned and social public in various ways, conducted trial design and evaluation on the strengthening effects, thereafter modified main provisions repeatedly, and finalized this Code through review.

This Code comprises 13 chapters and 2 appendixes and the main technical contents cover general provisions, terms and symbols, basic requirements, materials, reinforced concrete layer strengthening, steel reinforcement mesh mortar layer strengthening, sectional steel strengthening, external prestressed strut strengthening, bonded fiber reinforced polymer strengthening, wire rope mesh-polymer modified cement mortar layer strengthening, strengthening with adding masonry counterfort column, construction strengthening of masonry structures and masonry crack repairing.

The provisions printed in bold type in this Code are compulsory ones and must be enforced strictly.

The Ministry of Housing and Urban-Rural Development is in charge of the administration of this Code and the explanation of the compulsory provisions; and Sichuan Institute of Building Research is responsible for the explanation of specific technical contents. All relevant organizations are kindly requested to sum up your experiences and accumulated data and information in actual practices during the process of implementing this Code so as to enrich and improve the quality of this Code. The relevant opinions and advice, whenever necessary, can be posted or passed on to Sichuan Institute of Building Research (Address: No. 55, North Third Section, First Ring Road, Chengdu City, 610081, China).

Chief development organizations of this Code:

Sichuan Institute of Building Research

China Huashi Enterprises Company Limited

Participating development organizations of this Code:

Hunan University

Tongji University

Harbin Institute of Technology

Fuzhou University

Wuhan University

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Contents

1 General Provisions

1.0.1 This Code was formulated with a view to achieving reliable technology, safety and usability, economy and rationality and guaranteed quality for strengthening of masonry structures.

1.0.2 This Code is applicable to strengthening design of buildings and general masonry structures.

1.0.3 Before strengthening of masonry structures, reliability appraisal shall be carried out, on basis of building types, according to the relevant requirements of the current national standards GB 50144 *Standard for Appraisal of Reliability of Industrial Buildings and Structures* and GB 50292 *Standard for Appraiser of Reliability of Civil Buildings* respectively. Where it is carried out in combination with the seismic strengthening, seismic capacity appraisal also shall be carried out according to the relevant requirements of the current national standard GB 50023 *Standard for Seismic Appraisal of Buildings*.

1.0.4 Strengthening design of masonry structures shall meet not only those specified in this Code, but also the requirements of the current relevant standards of the nation.

2 Terms and Symbols

2.1 Terms

2.1.1 Strengthening of masonry structures

Measures such as strengthening, partial replacement or internal force adjustment are taken for masonry structures with insufficient reliability or whose reliability is required to be improved by the Owner as well as the structure member and the relevant parts so as to make them have safety, durability and applicability specified in the current codes for design and required by the Owner.

2.1.2 Existing structure member

The original member before strengthening.

2.1.3 Important structure member

The structure member whose failure will affect or endanger the safe operation of the bearing structure system.

2.1.4 General structure member

Structure members other than the important structure members.

2.1.5 Composite cement mortar

The mortar with cement and high-performance mineral admixture as main components and mixed with additive and short fine fiber.

2.1.6 Polymer modified cement mortar

The high-strength cement mortar mixed with modified epoxy emulsion or other modified copolymer emulsion. The polymer modified cement mortar for the bearing structure shall be able to significantly imporove the capacity of its substrates such as anchored reinforcement, bonded concrete and masonry.

2.1.7 Steel reinforcement mesh

The mesh welded with ordinary hot-rolled ribbed bars or cold-rolled ribbed bars.

2.1.8 Fiber reinforced polymer

A kind of composite material with fiber reinforcement effect that are arrayed with high-strength continuous fiber according to certain rules and formed after dipping, bonding and curing with adhesives, which is generally referred to as the fiber reinforced polymer.

2.1.9 Strength utilization factor of material

The calculation factor introduced considering that the strength of strengthening materials fails to be fully utilized under the secondary load.

2.1.10 External layer strengthening

A kind of strengthening method that the bearing capacity and stiffness of the existing structure member are improved through external reinforced concrete layer or steel reinforcement mesh mortar layer.

2.1.11 Sectional steel strengthening

A kind of strengthening method that the section steel limb and batten plate are welded into a structure for the masonry column enclosure and the external force is distributed according to their

respecitive stiffness ratios, which is also referred to as dry external sectional steel strengthening.

2.1.12 External prestressed strut strengthening

A kind of strengthening method that precompression is applied to two diagonal steel struts with cut and bending through tightening the transverse screw rod device so as to discharge the load of the masonry columns to the strut.

2.1.13 Counterfort masonry column strengthening

A kind of strengthening method that partial wall is thickened at some distance along the length direction of the masonry wall to form stiffening wall with buttress.

2.1.14 Masonry crack repairing

A kind of repairing or restoring method adopted with a view to sealing the masonry crack or recovering the integrity of the cracked masonry.

2.2 Symbols

2.2.1 Material performance

E_m——the elastic modulus of the masonry member of the existing structure;

E_a—— the elastic modulus of the new section steel;

E_f——the elastic modulus of the new fiber reinforced polymer;

f_{m0}, f——the design values for the compression strength of the existing masonry and new masonry respectively;

f_c——the design value for the axial compressive strength of the new concrete;

f_y, f'_y——the design values for tensile and compression strength of the new reinforcement;

f_f——the design value for the tensile strength of the new fiber reinforced polymer.

2.2.2 Action effect and bearing capacity

N——the design value for axial compression after strengthening of structure member;

M——the design value for the bending moment after strengthening of structure member;

V——the design value for the shear force after strengthening of structure member;

δ_s——the tensile stress of the reinforcement.

2.2.3 Geometric parameters

A_{m0}——the sectional area of the existing structure member masonry;

A_c——the sectional area of the new concrete;

A_s——the sectional area of the new reinforcement;

A_a——the total sectional area of the new section steel (angle steel);

h——the height of the strengthened section of structure member;

h_0——the effective height of the strengthened section of structure member;

b——the rectangular section width of the existing structure member;

I_{m0}——the section inertia moment of the existing structure member;

I_a——the section inertia moment of the steel frame;

H_0——the calculated height of the structure member;

h_T——the reduced thickness of the wall section with couterfort column.

2.2.4 Calculation factors

β——the height—thickness ratio of the masonry structure member;

α_c——the strength utilization factor of the new concrete;

α_s——the strength utilization factor of the new reinforcement;

α_f——the participation factor of the fiber reinforced polymer;

α_m——the strength utilization factor of the new masonry;

φ_{com}——the stability factor of the masonry structure member under combination of axial compression;

K_m——the stiffness degradation factor of the existing masonry;

η——the cooperation factor;

ρ_f——the volume ratio of the circumferential enclosure bundle.

3 Basic Requirements

3.1 General Requirements

3.1.1 Where the masonry structures require strengthening through the confirmation of reliability appraisal, strengthening design shall be carried out by qualified professionals upon the appraisal conclusion and the Client's requirements as according to the requirements of this Code and the Owner. The strengthening design range may be determined according to the whole building or its some independent sections, or designated structure, structure member or connection; however, the overall firmness of this structure shall be considered and comprehensive consideration of energy conservation and environmental protection requirements shall be taken for both of them.

3.1.2 In the strengthening design, if the existing masonry structure is discovered without ring beam and constructional column, or parts related to overall firmness of the structure is without tie, anchorage and necessary support or these construction measures are insufficient or improper, supplement or renovation shall be carried out in this strengthening design.

3.1.3 The safety grade of the masonry structures after strengthening shall be agreed by the Client and the Designer, on the basis of the structural damage consequence severity, the structure importance and strengthening design service life, according to actual conditions.

3.1.4 Scientific and reasonable plan shall be selected according to the structure characteristics for the strengthening design of masonry structures and shall be closely intergrated with the actual construction methods; effective measures shall be taken so as to guarantee reliable connection between new structure members as well as components and existing structures. New section and the existing section shall be bonded firmly for integral coordination and any adverse influence on the unreinforced part, relevant structure, structure member, subgrade and foudation shall be avoided.

3.1.5 Effective prevention and control measures shall be put forward in the strengthening design for the existing structure damage due to such influencing factors as high temperature, high humidity, low temperature, freeze thawing, chemical corrosion, vibration, temperature stress, uneven subgrade settlement; treatment and strengthening shall be carried out in the sequence specified in the design.

3.1.6 Comprehensive consideration of technical and economical effect shall be taken for the strengthening design of masonry structures and the design shall be free from structures with very poor strengthening repair-suitability as well as unnecessary dismantling or replacement.

Note: structures with very poor repair-suitability refer to the ones whose total strengthening costs reach over 70% of total cost of the constructed structure, excluding cultural relic buildings and other buildings with historical value or artistic value.

3.1.7 For masonry structures with potential inclination, unstability, oversize deformation or collapsion in the strengthening process, effective temporary safety measures shall be put forward in the strengthening design document and it shall be defined that the construction organization must strictly implement them.

3.1.8 The strengthening design service life of the masonry structures shall be determined according to the following principles:

1 The service life of the structure after strengthening shall be agreed by the Owner and the design organization.

2 Generally, it should be considered according to 30 years; at the expiration, stress shall be laid upon the new reliability appraisal; if the structure is considered to be in normal working state, its service life still can be extended.

3 For bonded structures and structure members or reinforced ones mixed with polymer for strengthening, their working states shall be inspected regularly and the inspection interval may be determined by the design organization, but the first inspection time shall be less than 10 years (including).

3.1.9 Without technical appraisal or design licensing, the use and service environment of the masonry structures after strengthening shall not be changed.

3.2 Principles for Calculation of Design

3.2.1 For structural analysis method adopted in the strengthening design of masonry structures, generally, linear elasticity analysis method shall be adopted to calculate the structure action effect and it shall meet the relevant requirements of the current national standard GB 50003 *Code for Design of Masonry Structures*.

3.2.2 Where the masonry structures are strengthened, load bearing capacity design and checking shall be carried out according to the following requirements and shall meet the requirements of the normal functinos.

1 Structural action shall be verified through investigation or inspection and the characteristic value or representative value shall be determined according to requirements of Appendix A in this Code.

2 Action effect of the strengthened structure and structure member shall be determined according to the following requirements:

1) Calculation chart of the structure shall meet requirements of actual stress and structure;
2) Combination for action effects and the combination facor as well as partial factor for the action shall be determined according to the relevant requirements of the current national standard GB 50009 *Load Code for the Design of Building Structures* and additional internal force caused by actual load eccentricity, structural deformation and temperature action shall be considered.

3 Measured size shall be adopted for the existing structures and structure members while nominal value given in the strengthening design document may be adopted for that of new ones.

4 Masonry strength grade of the existing structures and structure members and characteristic value of tensile strength of stressed reinforcement shall be taken according to the following requirements:

1) Where the original design document is valid and the structure is free from the doubt of serious performance degradation, the original design value may be adopted;
2) Where site inspection shall be carried out for the structures through reliability appraisal, the characteristic value presumed according to inspection results shall be adopted.

5 Performance and quality of strengthening materials shall meet the requirements of Chapter 4 in this Code; and the characteristic value of its performance shall be determined according to those specified in Article 3. 2. 3 of this Code and the design value for its performance shall be adopted according to requirements of the relevant chapters.

6 Where the bearing capacity of the structures and structure members is checked, actual stress conditions of the existing structures in the strengthening shall be considered, including strain lagging characteristic of strengthened part and coordination between the strengthened parts and existing structures.

7 Where the transmission line is changed or the structural mass is increased after the strengthening, necessary checking shall be carried out for relevant structures and structure members as well as building subgrade and foundation.

8 Strengthening of the structures and structure members in the seismic fortification area shall meet the requirements of the bearing capacity and be rechecked for the seismic capacity; they shall be free from new weak area due to local strengthening or sudden stiffness change. In addition, increasing earthquake action effect due to increasing structural stiffness also shall be considered.

Note: strengthening methods in this Code generally may be used for seismic strengthening of the structures; however, with regard to the design, calculation and construction, they shall be adopted according to the relevant requirements of the current national standard GB 50011 *Code for Seismic Design of Buildings* and the current professional standard JGJ 116 *Technical Specification for Seismic Strengthening of Building*.

3. 2. 3 Characteristic value of performance of the strengthening materials (f_k) shall be determined, on the basis of sampling inspection results, according to the following formula:

$$f_k = m_f - k \cdot s \tag{3. 2. 3}$$

Where,

m_f——the average material strength calculated according to n test pieces;

s——the standard deviation of material strength calculated according to n test pieces;

k——the calculation factor for characteristic value of the material strength related to α, c and n; it is obtained by looking up Table 3. 2. 3;

α——the lower quantile under normal probability distribution; $\alpha=0.05$ shall be taken for it according to 95% guarantee rate required by the characteristic value of the material strength;

c——Where confidence level adopted for performance of the strengthening materials is inspected, generally for steels, $c=0.90$ may be taken; for concrete and timber, $c=0.75$ may be taken; for masonry, $c=0.60$ may be taken; for other materials, it is specified in the relevant chapters of this Code.

Table 3. 2. 3 Calculation Factor k for Characteristic Value of the Material Strength

n	k value ($\alpha=0.05$)				n	k value ($\alpha=0.05$)			
	$c=0.99$	$c=0.90$	$c=0.75$	$c=0.60$		$c=0.99$	$c=0.90$	$c=0.75$	$c=0.60$
4	—	3. 957	2. 680	2. 102	15	3. 102	2. 329	1. 991	1. 790
5	—	3. 400	2. 463	2. 005	20	2. 807	2. 208	1. 933	1. 764
6	5. 409	3. 092	2. 336	1. 947	25	2. 632	2. 132	1. 895	1. 748
7	4. 730	2. 894	2. 250	1. 908	30	2. 516	2. 080	1. 869	1. 736
10	3. 739	2. 568	2. 103	1. 841	50	2. 296	1. 965	1. 811	1. 712

3.2.4 In order to prevent collapse due to sudden failure of strengthened part of the structure, where strengthening with adhesives or mixing with polymer is adopted, the strengthening design shall be carried out according to those specified in this Code and checking shall be carried out for the existing structures. During the checking, the existing structures and structure members shall be able to bear n times of action of characteristic value of the dead load. Where the ratio of the characteristic value of the variable load (excluding earthquake action) to the characteristic value of the permanent load is less than or equal to 1, 1.2 shall be taken for n; where the ratio is greater than or equal to 2, 1.5 shall be taken for n; meanwhile, it is determined according to linear interpolation.

3.3 Strengthening Methods and Technology

3.3.1 The srengthening of masonry structure may be divided into direct strengthening and indirect strengthening. During the design, appropriate strengthening methods and technology may be selected according to structure characteristics, actual conditions and service requirements.

3.3.2 For direct strengthening, external layer strengthening, sectional steel strengthening, bonded fiber reinforced polymer strengthening and external counterfort masonry column strengthening should be selected according to actual engineering conditions.

3.3.3 For indirect strengthening, external prestressed strut strengthening and strengthening by changing calculation chart of the structure should be selected according to actual engineering conditions.

3.3.4 Crack repairing, tie and anchorage technology in accordance with those specified in this Code shall be adopted.

4 Materials

4.1 Masonry Materials

4.1.1 Blocks of the same variety as that of the existing structure members shall be adopted for the strengthening of masonry structures; the blocks shall not be inferior to first-class products and the strength grade shall be determined according to the original design grade of the block and shall be greater than or equal to MU 10.

4.1.2 For cement mortar for the external layers of masonry structures, if it is designed to ordinary cement mortar, the strength grade shall be greater than or equal to M10; if it is designed to composite cement mortar, the strength grade shall be greater than or equal to M25.

4.1.3 For masonry mortar for strengthening masonry structures, cement mortar or cement-lime composite mortar may be adopted; however, for the damp-proof layer, basement and other humid positions, cement mortar or composite cement mortar shall be adopted. In any case, masonry mortar with large contractility shall not be adopted. Compression strength grade of the strengthening masonry mortar shall be one grade higher than that of the existing mansory mortar and shall be greater than or equal to M10.

4.2 Concrete Materials

4.2.1 For strengthening cement of masonry structures, Portland cement and ordinary Portland cement with strength grade no less than Grade 32.5 shall be adopted; Portland slag cement or Portland pozzolana cement may also be adopted, but the strength grade shall be greater than or equal to Grade 42.5; where necessary, rapid-hardening Portland cement or composite Portland cement also may be adopted.

Notes: 1 Where corrosion resistance and high-temperature resistance requirements are provided for the strengthened structures, corresponding special cement shall be adopted.

2 Where cement for polymer modified cement mortar and composite cement mortar is prepared, the strength grade shall be greater than or equal to Grade 42.5 and shall meet the requirements of the product specification.

4.2.2 Performance and quality of the cement shall meet the relevant requirements of the current national standards GB 175 *Common Portland Cement* and GB 199 *Rapid Harding Portland Cement* respectively.

4.2.3 In the strengthening engineering of masonry structures, aged cement, dampened cement and mixed cement as well as cement without delivery certificate and qualified site inspection must not be used.

4.2.4 Where structure strengthening concrete is prepared, the variety and quality of its aggregate shall meet the following requirements:

1 Hard and durable crushed stone or pebble shall be selected for the coarse aggregate and the maximum grain size shall meet the following requirements:

1) It should be less than or equal to 20mm for the on-site mixed concrete;

2) It should be less than or equal to 12mm for the sprayed concrete;