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CRACKING AND BEARING CAPACITY OF REPAIRED REINFORCED CONCRETE WALL-FLOOR JOINTS

Alg. Kudzys

1. Introduction

During building operation life, unanticipated intensity lateral forces caused by wind storm gusts, earthquake or other natural powers can damage load carrying reinforced concrete structures. Vertical and transverse cracks caused by lateral reversal loads lower not only the stiffness and the cracking resistance of structural members, but also their strength in normal and diagonal sections. When destruction and residual displacement of the load carrying structures and, first of all, the wall-floor connections, are not great, the generated cracks or local flaking areas can be repaired. Reconstruction or repairing of damaged structural members and the strengthening of their joints involves a lot of complicated problems, which are in close relation with economical factors, strength reversion investigations, ensuring structural durability as well as the reliability of the repaired structures.

One more quite significant reason for the requirement of experimental research on renovation properties of structural members is a rather complicated evaluation of load carrying structures strength after repair on the construction site. By means of non-destructive testing methods, which are usually applicable, it is possible to obtain sufficient information on the mechanical properties of the materials used, but the data on the bearing capacity of reinforced concrete structures is not as reliable as in

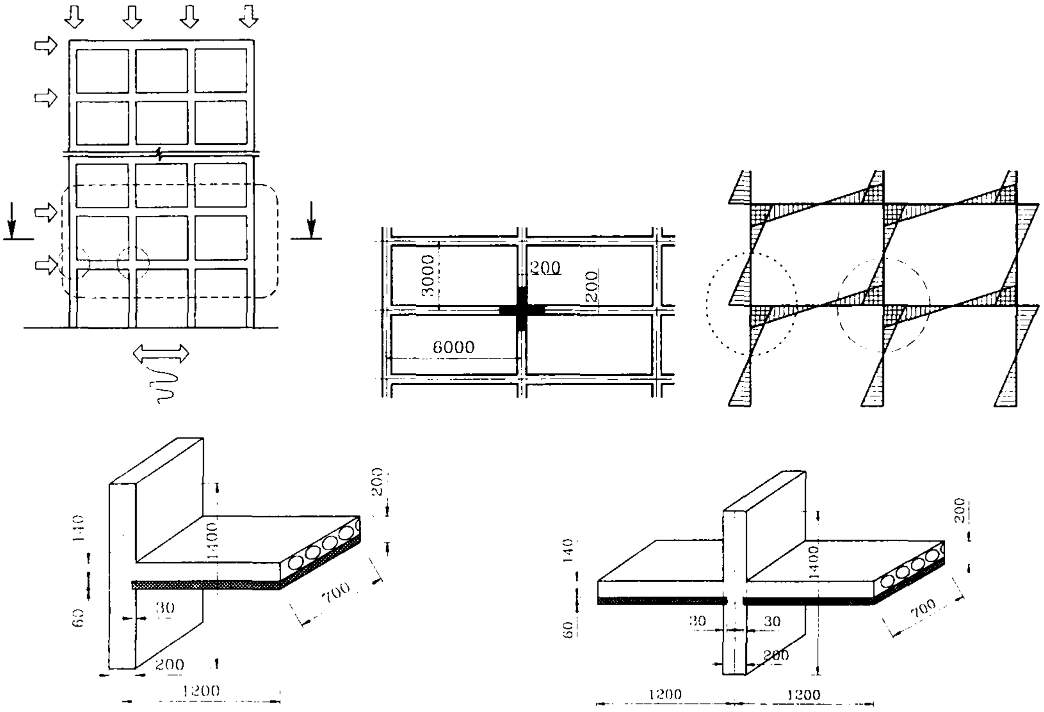

Fig 1. Arrangement of interior and exterior wall-floor connections in multistory building

a destruction test under the actual loading conditions at a research laboratory. That is why experimental research on the strength and failure performances of wall-slab connections under vertical and lateral loading would not be sufficient without an additional analysis on the strength and failure behaviour of the same structures after repair.

The main purpose of the experimental and theoretical studies presented in this article is the acquaintance with the strength and stiffness regeneration possibilities, and renovation of the cracked wall-floor connections after they accepted the ultimate lateral load.

2. Outline of Specimen Variables and Loading Method

The size of the wall-floor connection specimen was chosen with a view to make a full-scale experimental model which simulated structural members and their joints on the lowest story of a multistory residential building. Under the above considerations the length of a floor slab member was about 1/5 of the full-scale span length and the height of wall members was about 1/5 of the full-scale story height (Fig 1). All members, exept 60 mm depth precast slabs (concrete compressive strength f_c=35...40 MPa) in the composite flooring, were made from cast-in-situ concrete (f_c=20...27 MPa).

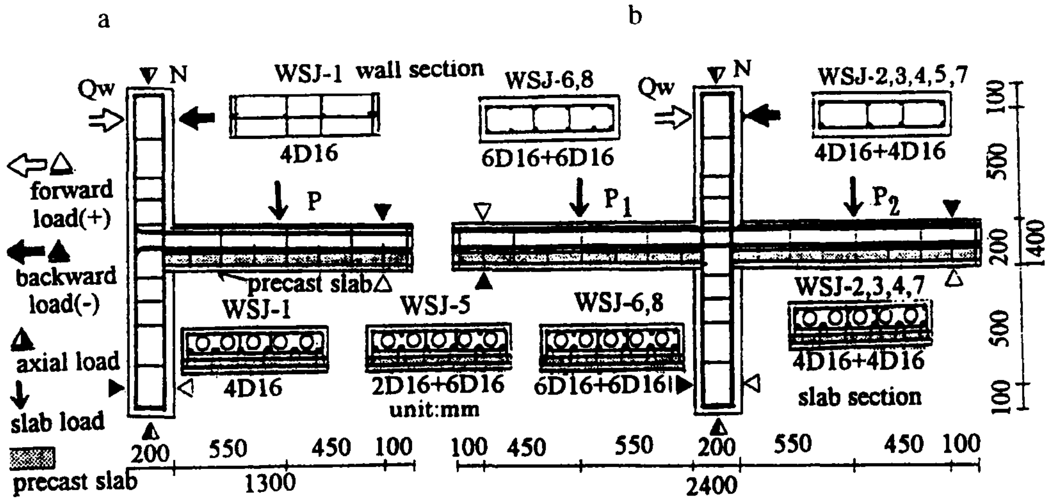

Fig 2. Outline of experimental exterior (a) and interior (b) wall-floor connection specimens

Table 1. Variables of wall-floor connection specimens and vertical loads

Specimen Number	Longitudinal Reinforcement		Wall Axial		Floor Load P, kN	Specimen Type
	Wall	Floor	Load N, kN	Stress		
WSJ-1(1R)	4ϕ16	**4ϕ16	345	$f_c/10.6$	16.2	interior
WSJ-2 (2R)	4ϕ16+4ϕ16	*4ϕ16+**4ϕ16	295	$f_c/10.7$	16.2	interior
WSJ-3 (3R)	4ϕ16+4ϕ16	*4ϕ16+**4ϕ16	570	$f_c/6.60$	23.5	interior
WSJ-4 (4R)	4ϕ16+4ϕ16	*4ϕ16+**4ϕ16	490	$f_c/5.50$	16.2	interior
WSJ-5 (5R)	4ϕ16+4ϕ16	*2ϕ16+**6ϕ16	325	$f_c/10.4$	16.2	interior
WSJ-6 (6R)	6ϕ16+6ϕ16	*6ϕ16+**6ϕ16	520	$f_c/6.30$	23.5	interior
WSJ-7 (7R)	4ϕ16+4ϕ16	*4ϕ16+**4ϕ16	195	$f_c/15.6$	16.2	exterior
WSJ-8 (8R)	6ϕ16+6ϕ16	*6ϕ16+**6ϕ16	295	$f_c/10.3$	16.2	exterior

*: floor upper reinforcement; **: floor bottom reinforcement; R - repaired specimen.

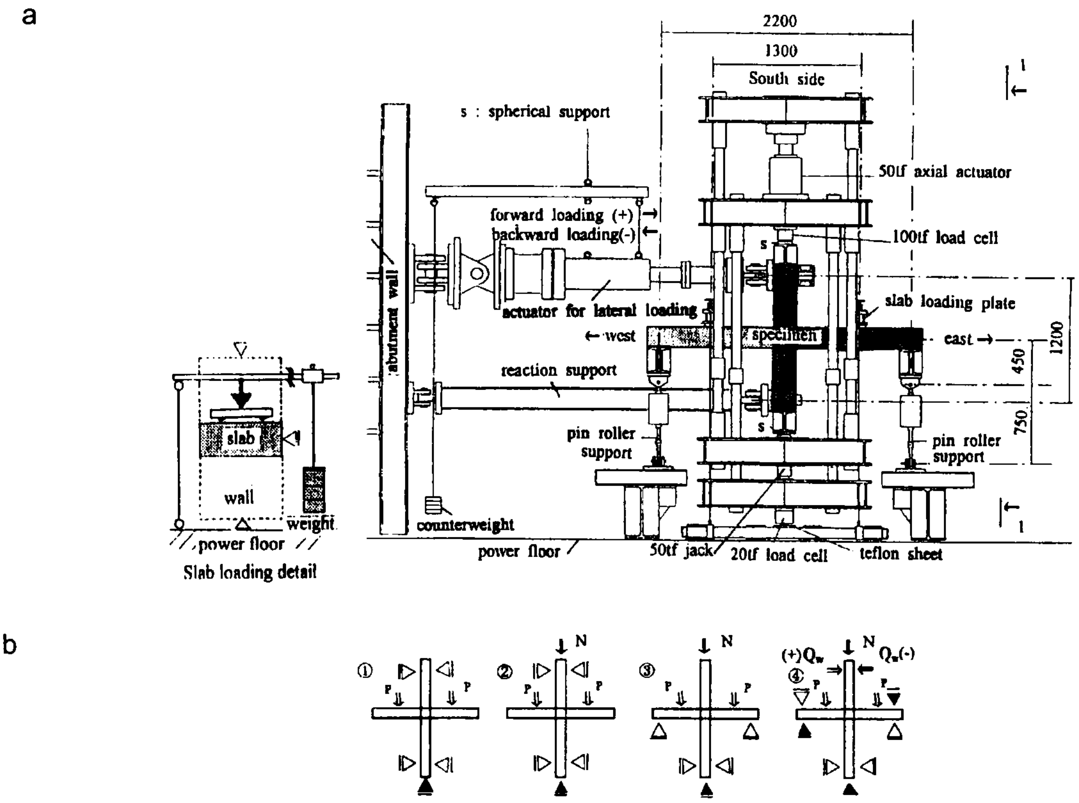

Fig 3. Equipment for vertical and reversal lateral loading of specimens (a) and their loading order (b)

Hollows in the composite flooring were formed by ϕ76 mm plastic pipes. The main longitudinal reinforcement for wall and floor structures were ϕ16 mm bars ($\sigma_y = 370...390$ MPa), shear reinforcement for all members and welded mesh for the precast slabs were 6 mm bars ($\sigma_y = 390$ MPa) as shown in Fig 2, Table 1 and references [1, 2].

In order to simulate the load conditions of acting vertical and reversal lateral forces with a view to compare the test results with primary wall-floor connection specimens experiment data, the same load equipment was used (Fig 3a).

After the floor (Fig 3b, 1) and wall members (Fig 3b, 2) were subjected to vertical loads (load values are presented in Table 1), the slab supports were fixed and an actuator for lateral loading was released to free position. Lateral reversal load (Fig 3b, 4) was provided by the displacement control of story drift angle R at 0.1 %, 0.2 %, 0.5 %, 1 %, 2 %, 3 % and 4 %.

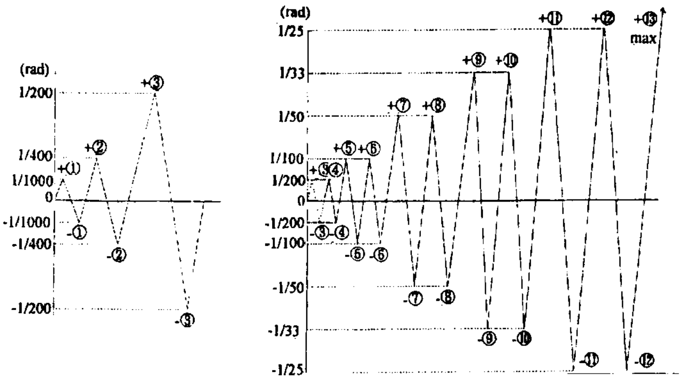

Fig 4. Loading program for wall-floor specimens

The loading program in the displacement controlled test for specimens with mended cracks was provided under the same loading conditions as the new ones, exept that the reversal load at each displacement angle R was done without repeating the same cycle once more (loading cycles ±4, ±6, ±8 and ±10 in Fig 4 were not conducted).

3. Repair of Cracked Connections

In construction practice there is a number of different methods for mending and repairing damaged areas in cracked structures. In some cases cast-in-situ concrete casting with reinforcement mesh or additional reinforcement can be set to fix the damaged one with a view to increase flexural stiffness. When the bearing capacity is reduced only by intensive concrete cracking but the reinforcement steel mechanical properties are still satisfactory, an injection by self-flow of polymer glues into the cracks can be applied. Considering wall-floor connection specimens, which cracked in the joint core area but did not have residual displacements after the previous overloading (the specimens were purposely returned to the initial vertical position by the actuator), it was supposed to mend only the developed flaking areas.

Eight previous tested interior and exterior cast-in-situ reinforced concrete wall-composite multihollow floor connection specimens were repaired by replacing severe damaged cover concrete with epoxy mortar and by injection of epoxy resin by means of plastic cylinders and special injector into cracks and other openings, which appeared after the connections failed under ultimate lateral loading. Three types of epoxy resin consisted of main and hardening components were used for the crack repair. Inspite of the different penetration ability and density, all resins were almost of the same strength (R_c = 116 ... 118 MPa, R_t = 68 ... 74 MPa). The mechanical properties of the materials were obtained from the compression and bending tests of epoxy resin prisms.

It was needed to develop a procedure which allows the determination of the strength of the concrete in an actual structure. It is important to ascertain the real strength of the concrete in new structures, as well in old ones. The concrete strength evaluation of repaired wall-floor connections in our experiments was undertaken with a view to separate the strengthening effect by the epoxy resin injection from the strengthening of the specimen concrete due to time. The first specimen series (WSJ-1R, 2R, 3R) were tested without an additional concrete strength inspection and significant increase in the strength of the repaired specimens aroused some suspicions about the concrete strengthening in time (after six months) as a possibility . At the same time the connection slab main reinforcement bars were taken out from the specimens to assure that the steel yield during the previous experiment did not provide reinforcement strengthening in tensile. Before the repaired specimens experiment the concrete strength was tested by rebound method using Schmidt Hammer. Nevertheless, a significant strengthening effect neither in reinforcement nor in concrete was observed.

4. Cracking and Failure Behaviour

The cracking and failure performances of wall-floor connection specimens with mended cracks were close to the new ones (Fig 5). However, cracks did not arise at the same places as in the new specimens and cracks amount was less [3].

In specimen *WSJ-1R*, the small initial bending cracks at the wall-floor adjoining section predominated during the experiment and the specimen failed by the slab flexible yielding.

As for specimens *WSJ-2R and WSJ-4R*, shear cracks in the joint core were at a considerably low lateral force and in small quantities, thus differing from the new specimens experiment. Later the joint core deformation considerably increased the joint core failed in shear.

Vertical and transverse cracks in the specimen *WSJ-3R* joint area did not develop intensively at the beginning. Later shear cracks generated in the centre of the joint core. The failure was in close relation with both the shear and the bending cracks expansion, and bearing capacity was reached by the shear and flexural failures at the same time.

The floor loading initiated small bending cracks in both floor members of the specimen *WSJ-5R*. Shear cracks in the centre of the joint core were observed,

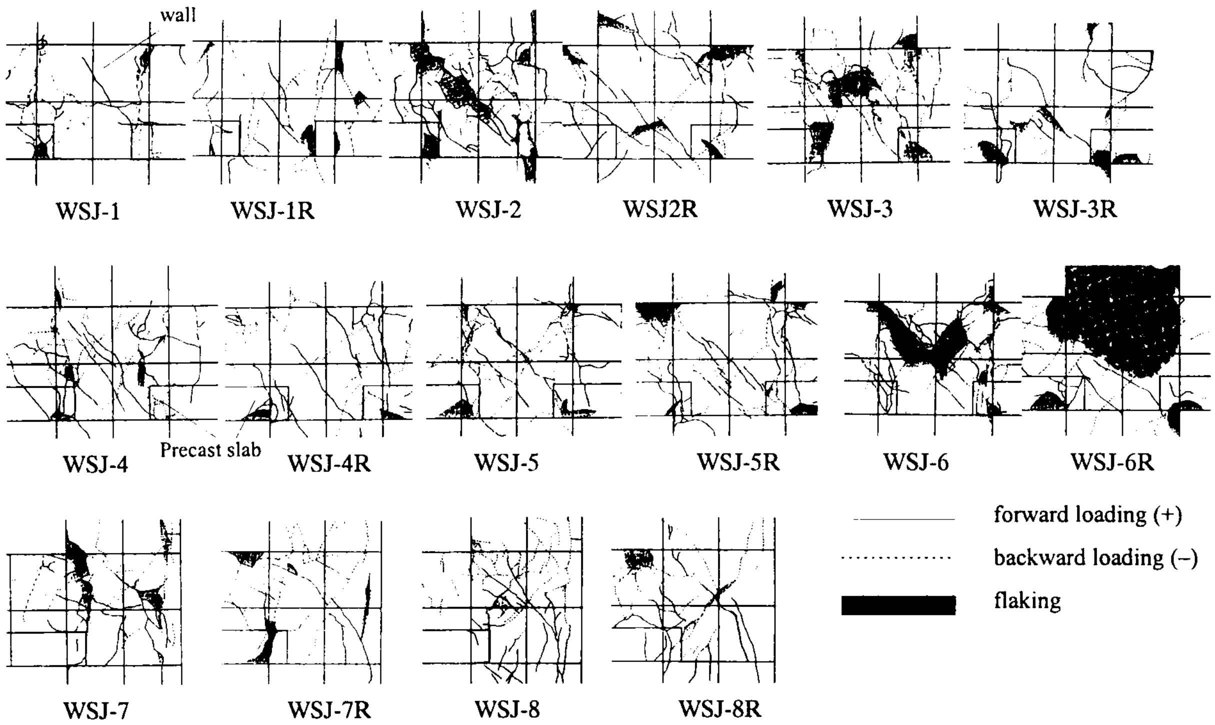

Fig 5. Final cracking arrangement in joint core of wall-floor connections (indeces of repaired ones with letter R)

but did not spread later, and ultimate bearing capacity was reached by floor members flexural failure.

Bending cracks in the wall-floor joint area of *WSJ-6R* specimen developed from the first loading cycles but their width did not increase considerably. The specimen reached its ultimate bearing capacity with flaking at the joint core caused by shear cracks.

Exterior wall-slab connection specimens *WSJ-7R* and *WSJ-8R* subjected to forward lateral wall force (tensile action effects generated in the precast part of the composite slab) reached ultimate bearing capacity by floor flexural failure. Shear cracks in joint core of specimen *WSJ-7R* at backward developed at the bent hooks of floor main reinforcement and penetrated into the upper and lower wall members. The flaking zones developed in the joint core and the ultimate strength was reached by core concrete shear and reinforcement adhesion failure.

Due to an increase of shear cracks and their width in the joint core in specimen *WSJ-8R*, bending cracks did not develop so intensively and the shear failure predominated.

Table 2. Strength of the repaired wall-slab connection specimens versus new ones

Specimen	Q_{wu} (+/-), kN	Q_{wRu}(+/-), kN	Q_{wRu} / Q_{wu} (+/-)	κ (%)
WSJ-1(WSJ-1R)	53.1/45.0	59.9/54.2	1.13/1.21	13/21
WSJ-2(WSJ-2R)	90.6/84.7	96.7/84.7	1.07/1.00	7/0
WSJ-3(WSJ-3R)	92.9/85.0	90.6/94.5	0.98/1.11	-2/11
WSJ-4(WSJ-4R)	95.1/86.9	101.4/97.7	1.07/1.12	7/12
WSJ-5(WSJ-5R)	95.5/91.1	99.6/90.7	1.04/1.00	4/0
WSJ-6(WSJ-6R)	131.4/122.6	123.6/103.0	0.94/0.84	-6/-16
WSJ-7(WSJ-7R)	24.2/50.2	28.1/63.9	1.16/1.27	16/27
WSJ-8(WSJ-8R)	35.8/81.4	33.7/88.8	0.94/1.09	-6/9

Notes: Q_{wu} - ultimate lateral load for new specimens; Q_{wRu} - same, for repaired ones

(+/-) - forward lateral load/backward lateral load, κ : specimen strengthening ratio

4. Ultimate Strength

The main results of the ultimate bearing capacity of the repaired connections are presented in Table 2. All specimens showed successful strengthening except the heavily reinforced wall-floor connections. Since binding agents did not fill up many microcracks caused by reinforcement adhesion failure during the prior experiment outside the joint core, bond failure in the slab members led to a decrease in general bearing capacity of WSJ-6R and partly WSJ-8R repaired specimens.

5. Conclusions

1. Bending, shear and bond cracks in walls, floors and their connections caused by lateral reversal loading can be successfully mended by means of epoxy resin injection. However, it is necessary to determinate carefully the epoxy resin portions and injection sites in consideration to the fact of bond failure along longitudinal steel bars, when cracks do not appear on the surface of the concrete member and in heed of interior cracking.
2. Repairing by epoxy resin injection can even cause an increase of initial cracking resistance and ultimate bearing capacity in mended wall-floor connections.
3. Additional research is necessary for the determination of binding materials adhesion properties inside cracked reinforced concrete structures and for greater accuracy of mended structures strength evaluation.

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SUREMONTUOTŲ MONOLITINIŲ SIENŲ IR PERDANGŲ SANDŪRŲ PLEIŠĖJIMAS IR LAIKOMOJI GALIA

Alg. Kudzys

Santrauka

Nagrinėjamos supleišėjusių ar kitaip pažeistų pastatų laikančiųjų konstrukcijų bei jų sandūrų atstatymo ir remonto problemos. Jos ypač svarbios dėl tos priežasties, kad realaus pastato suremontuotų konstrukcijų laikomosios galios įvertinimas yra labai sudėtingas. Neardančiais bandymais pakankamai tiksliai galima nustatyti medžiagų fizines-mechanines savybes, tačiau konstrukcijos stiprumo įvertinimas negali būti patikimas, neatlikus laboratorinių eksperimentų su natūralaus dydžio modeliais.

Eksperimentinių tyrimų metu buvo išbandyti daugiaaukščių gyvenamųjų namų gelžbetoninių monolitinių sienų ir kompleksinių perdangų (surenkama 60 mm storio gelžbetoninė plokštė monolitinama iš 76 mm diametro plastmasinių vamzdžių suformuojant tuštumas ir betonuojant kartu su sienų elementais) sandūrų modeliai (1 pav.). Pleišėtumo, irimo pobūdžio ir stiprumo analizei buvo naudojami natūralaus dydžio šeši pastato vidinių sienų ir perdangų sandūrų mazgai bei du išorinių sienų ir perdangos bandiniai (2 pav.). Pagrindiniai kintamieji eksperimentų metu buvo sienų ir perdangų armatūros kiekis bei vertikaliosios apkrovos dydis (1 lentelė).

Suremontavus sandūrų bandinius (injektavus po spaudimu epoksidinę dervą į pažeistas konstrukcijų zonas) po anksčiau atliktų laikomosios galios nustatymo eksperimentinių tyrimų, jie buvo pakartotinai paveikti kintamosiomis vertikaliosiomis ir horizontaliosiomis apkrovomis. Apkrovimui buvo panaudota speciali įranga su apkrovos pulsatoriais laikantis apkrovimo eiliškumo, koks buvo taikytas bandant naujus bandinius (3 pav.). Horizontalioji apkrova buvo perduodama per reversinį pulsatorių kontroliuojant poslinkio R dydį (4 pav.). Bandinių irimo pobūdis, pleišėtumas bei stiprumas buvo palyginti su naujų mazgų bandymo rezultatais (5 pav., 2 lentelė).

Algirdas KUDZYS. Doctor (Technical sciences, Lithuania), Doctor (Engineering, Japan), Associate Professor. Dept of Building Structures. Faculty of Architecture. Vilnius Gediminas Technical University, 11 Saulėtekio Ave, Vilnius 2040, Lithuania, e-mail: kudzys@ar.vtu.lt

Graduate of Vilnius Civil Engineering Institute (1979). First Doctor degree in 1985 (building structures) at Lithuanian Institute of Building and Architecture. Probation and doctoral course studies at Hokkaido University (Japan) in 1990-95. Second Doctor degree in 1995 (engineering structures) at Hokkaido University. Member of Japan Concrete Institute and Architectural Institute of Japan (1993-96). Author of about 50 articles and manuals. Research interests: joints of reinforced concrete structures, computer simulation and design of reinforced concrete structures, renovation of buildings.