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Experimental investigation on ductility of the 105-storey hotel R.C. building structure

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Abstract:This paper concerns an experimental research of the vital elements of a building and the control of quality,to improve ductility of 105 storeys Ryugyong Hotel building structure in Pyongyong,D.P.R.of Korea. The tests was performed for the cyclic loading with the 1:10 scale model of the building's wing consisted of the monolithic transveres and longitudinal walls and and the floor slabs. As the result of the research,strength and ductility of the vital elements of a building was evaluated, and it was verified that the structural systems contained the sufficient stability to the design earthquake due to operating by the good high-strength concrete.

Description of the structural system

The Ryugyong Hotel which is consisted of a central 105 storeys tower,three 25th floor-additional buildings rising by *each of the tower wings and ground* floor part around the tower, had been settled in a location named Sojangdo-ng, in the Botongang district of Pyo-ngyang,D.P.R.of Korea and built on a site area of 60ha at 27.4m altitude on mainly new and weakly weathering sa-ndstone.

The hight of the 105 storeys tower is 321.3m and it's floor area is 320.000m^2.

The tower consists of three wings,56.4x18.9m(in plan) each,distributed ar-ound a central core-a cylinder with diameter 32.4m-under angle of 120°.

Up to the 25th storey the wings rise vertically,then taper up to the 81st floor (with a slope angle of 75.6°), where they vanish,while the central core starts to taper towads the top into a cone with the sam slope.

The spatial bearing wall system is formed as a combination of the reinf-orced concrete circular wall of the central core and both external and corridor walls of the wings and rein-forced concrete slabs.

The wall thickness varies in the fol-*lowing order:60cm for the cicular wa-*lls, up to the 35th floor;50cm,between 36th and 52th floor; 40cm above; 45cm for the external walls, up to 6th fl-oor; 35cm above; 55cm for the corrider walls,up to 6th floor; 35cm above,and

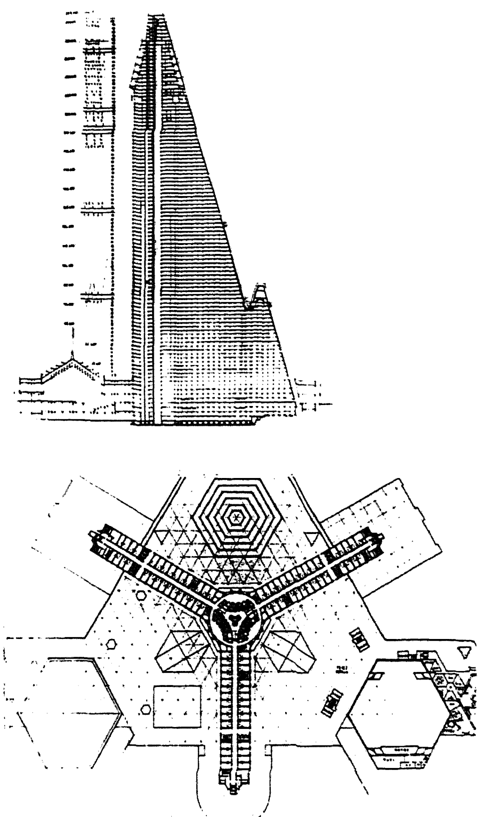

Fig.1 Vertical section and plan of the Ryugyong Hotel

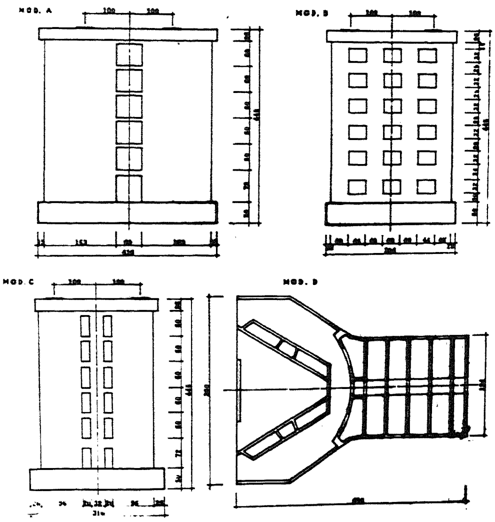

Fig.2 testing model

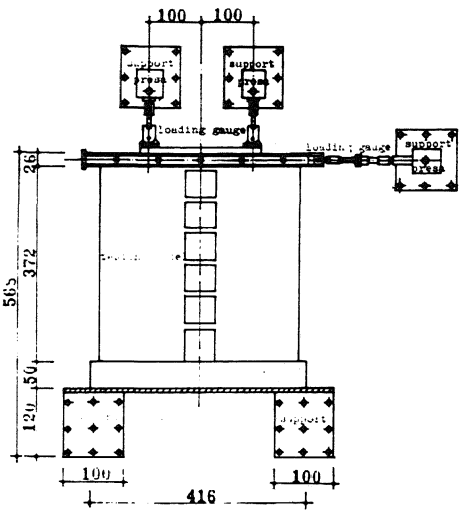

Fig.3 testing equioment

the floor slab is 14cm thick in the wings and 16cm in the cylindrical central core.

The foundation is a reinforced concrete box with 4.0m of height, 0.4m thick upper and 1.5m thick lower slab.

The vertical section and the first floor plan of the Ryugyong Hotel are presented in Fig.1.

Test on the vital structural elements

The design of the models for experimental testing was made up the basis of analytical study of the prototype

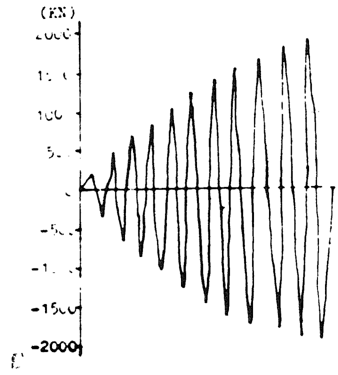

Fig.4 cyclic loading

building, and analysed for linear and nonlinear ranges.

The linear analysis of the prototype building showed that lower storey walls, where plastic hinges were formed during the seismic effects, were the most critical portions.

Therefore the results have been determined the dimensions and reinforcements of models for transverse and longitudinal walls,which was shown in the Fig.2.

In the contact between the wings and cylindrical core it proved that the adjacent parts of the 21st storey were the most critical portions.

Further a floor of the model is for the three floors of the real building and it shown in Fig.2.

The testing equipment consists of supporters, hydraulic jacks, connections between the model and the testing equipment, internal and external instrumentation and the data acquisition system.

Fig.3 shows general setup of testing equipment and the cyclic loading on the model are shown in the Fig.4.

The horizontal load was simulated by a hydraulic jack acting at the end of wing of the model.

The measuring instruments have automatic display of results, and all the results are directly recorded on magnetic tapes and stored for further data processing.

The following aspects of the model behaviour have been studied: strength, stiffness, deformations and ductility and failure mechanism of the model.

The strength of the model was considered at the characteristic loading stages of flextural cracks, yielding and ultimate strength.

The model deformations were considered for different loading conditions at yielding of reinforcement and ultimate deformation with the failure mechanism.

Table.1 .on and reinforcement of models

model	lW	w	lf	df	$A_s = A_s'$	A_{sv}	A_{sh}	$\frac{A_s}{lf \cdot df}$	$\frac{A_{sv}}{w \cdot 100}$	$\frac{A_{sh}}{w \cdot 100}$	$\frac{A_s}{lW \cdot w}$
	cm	cm	cm	cm	cm	cm/m	cm/m	%	%	%	%
mod.A	163	8	40	7	3.830	2.09	4.19	1.36	0.26	0.52	0.29
mod.B	40	7	7	7	0.785	1.96	2.09	1.60	0.28	0.30	0.29
mod.C	96	7	7	7	0.785	2.51	2.09	1.60	0.36	0.30	0.12
mod.D	194	8	38	7	1.010	5.02	5.02	0.38	0.63	0.63	0.06

lW:length of rib w :thickness of rib
lf :length of flange d :thichness of flange
A_s, A_s':area of tensile and compressive reinforcement,respectivelly
A_{sv} :area of vertical reinforcement in wall
A_{sh} :area of horizontal reinforcement in wall

Table.2 Strength properties of models

model	$\overset{T}{Q}_{cr}$ (KN)	$\overset{A}{Q}_{cr}$ KN	$\overset{T}{Q}_y$ KN	$\overset{A}{Q}_y$ KN	$\frac{\overset{T}{Q}_y}{\overset{A}{Q}_y}$	$\overset{T}{Q}_u$	$\overset{A}{Q}_u$	$\frac{\overset{T}{Q}_u}{\overset{A}{Q}_u}$
mod.A	246.0	275.0	380.0	426.5	0.89	411.1	566.8	0.73
mod.B	108.0	170.0	190.9	204.5	0.93	228.0	235.0	0.97
mod.C	157.0	165.4	146.0	211.0	0.69	175.0	251.0	0.70
mod.D	100.0	65.0	150.0	105.0	1.43	194.0	200.0	0.97

$\overset{T}{Q}_{cr}$, $\overset{A}{Q}_{cr}$;shear force at cracking stage in the test and the analysis,respectively
$\overset{T}{Q}_y$, $\overset{A}{Q}_y$;shear force at yielding stage in the test and the analysis,respectively
$\overset{T}{Q}_u$, $\overset{A}{Q}_u$;shear force at ultimate stage in the test and the analysis,respectively

Table.3 Deformations of the models

model	$\overset{T}{\Delta}_{cr}$ mm	$\overset{T}{\Delta}_{1y}$ mm	$\overset{A}{\Delta}_{1y}$ mm	$\overset{T}{\Delta}_{6y}$ mm	$\overset{A}{\Delta}_{6y}$ mm	$\overset{T}{\Delta}_{1u}$ mm	$\overset{A}{\Delta}_{1u}$ mm	$\overset{T}{\Delta}_{6u}$ mm	$\overset{A}{\Delta}_{6u}$ mm	$\overset{T}{D}_{\Delta 1}$	$\overset{T}{D}_{\Delta 6}$
mod.A	0.26	4.04	3.78	15.44	21.12	12.0	17.64	59.63	105.50	3.00	3.86
mod.B	1.85	4.42	3.42	20.49	18.00	18.10	15.54	37.92	43.89	1.83	1.85
mod.C	0.57	1.95	2.95	17.24	17.65	6.09	8.92	40.04	28.42	3.12	2.32
mod.D	1.11	3.14	4.23	-	-	16.22	18.10	-	-	5.17	-

$\overset{T}{\Delta}_{cr}$; cracking deformation in the test
$\overset{T}{\Delta}_{1y}$, $\overset{T}{\Delta}_{6y}$; yielding deformation of 1st and 6th storey in analysis,respectively
$\overset{A}{\Delta}_{1y}$, $\overset{A}{\Delta}_{6y}$; ultimate deformation of 1st and 6th storey in analysis,respectively
$\overset{T}{\Delta}_{1u}$, $\overset{T}{\Delta}_{6u}$; yielding deformation of 1st and 6th storey in test,respectively
$\overset{A}{\Delta}_{1u}$, $\overset{A}{\Delta}_{6u}$; ultimate deformation of 1st and 6th storey in test,respectively
$\overset{T}{D}_{\Delta 1}$, $\overset{A}{D}_{\Delta 6}$; ductility of 1st and 6th storey in test,respectively

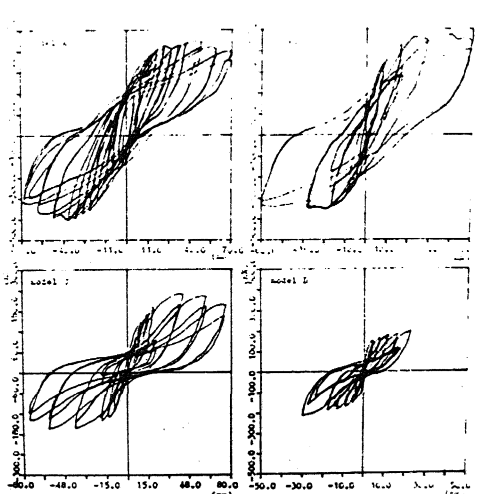

Fig.5 P-Δ hysteritic curve

The P-Δ hysteresis diagrams of the model, recorded during testing shows good behaiour of the energy absorption (Fig.5).

The experimental results of the model are compared with the analytical results. The dimensions of section of the member and reinforcement used in analysis, are presented in Table 1. The strength and deformation at the stage of cracking,yeilding and ultimate in the strength of the elements of the test model are presented in Table.2,3.

Quality control of High-strength concrete

The inspection of the quality of the model concrete was performed by the following three methods:(1) measuring the compressive strength of standard specimen in order to evaluate the qu-

Table.4 Properties of compressive strength for standard specimen

division	age 3	7	(day) 28	90	180	365
characteristic strength,KPa				4.5		
required strength,KPa				5.14		
number of specimen set	259	260	296	254	136	76
mean strength ,KPa	2.92	3.82	4.67	5.38	5.73	6.09
standard deviation,KPa	0.305	0.336	0.367	0.387	0.346	0.360
coefficient of deviation,%	10.3	8.9	7.9	7.2	6.0	5.9
rate of gain of strength,%	63.1	81.8	100	115	122.8	130.5

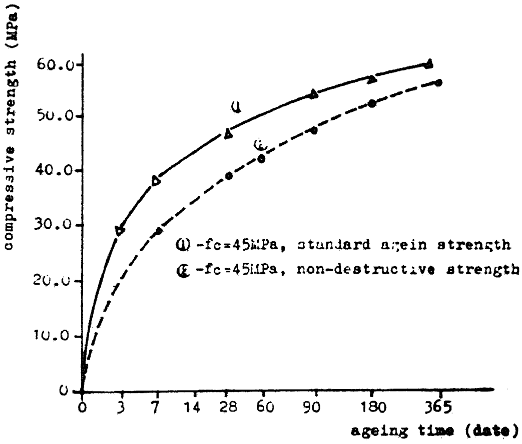

Fig.6 practical strength by non-destructive method of test

alitative properties of concrete(in situ) ; (2) measuring the real strength by non-destructive methods of test;(3) measuring the strength of the specimens extracted from structure

The (1) means that the mean values of the compressive strength for three specimens, respectively, with the age at 3,7,28,90,180,365 days were analysed ,the (2) shows the values measured 6 times according to the age of the real concrete in the (1), and the (3) tells the values of the 23 specimens in 2nd 10th storey walls with the age at 365 days.

The compressive strength of the standard specimen is presented in Table.4 ,while the real strength measured by the non-destructive method is shown in Fig.6.

Conclusion

The experimental testing was performed in order to determine the strength, deformation capability,ductility of the wing consisted of the opening shear walls,transverse and longitudinal walls and floor slabs, which made the reinforced concrete.

As the result of research it was determined that there is the sufficient strength and deformation capability in the opening shear walls and the contacts between cylinder and wings of the 105 storey Pyongyang Hotel building,and that there is the sufficient stability in the design earthquake by demonstrating the strength and the deformation capability of building in the experimental testing.

The mean strength of the specimen extracted from structure is the 5.25 KPa, the standard deviation-0.208 KPa and the coefficient of variation-5.7%.

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