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DEVELOPMENT AND STRUCTURAL DESIGN GUIDELINE FOR MEDIUM/HIGH-RISE RC WALL-FRAME STRUCTURES WITH FLAT-BEAMS

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SUMMARY

This manuscript reports about the medium/high-rise RC wall-frame structures (hereinafter called FB) , which have been developed by a joint research Building Research Institute and Urban Development Corporation (hereinafter called UDC). The main use of the FB is for apartment houses. The FB is construction of a reinforced concrete building composed of two frames, where the longitudinal-direction is provided with Wall-columns and Flat-beams. As a matter of fact the FB has been developed for the purpose of realization in "Comfort" and "Free dwelling unit plan". In the course of the FB, structural performance of the joint section with Wall-columns and Flat-beams was grasped, as well as structural experiment and analyses were conducted centering on the creating high-rise of the FB. The results of the study have been summarized in "Structural Design Guideline for Medium/High-rise RC Wall-Frame Structures (hereinafter called FB-Guideline). According to the FB-Guideline, concrete structural designing and seismic designing methods are being described, as well as structural and bar arrangement specifications reflecting upon the results of study have been summarized. In fact, the FB has been thus materialized, and actually the UDC is able to engage in designing and construction works.

INTRODUCTION

RC Wall construction structure is excellent in seismic safety. Since the Wall construction is composed of the shearing-walls, the structural members are featured by the simplification of a form work. On the contrary, structural regulations are stipulated (that is, the wall-frame structures must be joining rigidly with the shearing-walls, and the "Plane of structure" must be closed). In other words, it will be difficult to provide a large opening, and the existence of wall beams restricted the floor plan. In recent years, there is a tendency that dwellers prefer to have a spacious and flexible space. To satisfy such requirements, Building Research Institute and UDC started the study and development of the FB extended from the wall-frame structures. The FB can afford flexibility in floor plan, interior design as well as can afford apartment houses provided with comfortable space. In an early designing stage, the FB is featured by the 3

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planes of structure in the longitudinal direction up to 5-story. However, at present, in conformity with the requirements of flexibility in floor plan and of high-rise building, it is possible to design and construct FB featured by the 2 planes of structure in the longitudinal direction up to 11-story.

OUTLINE AND FEATURES OF RC WALL-FRAME STRUCTURES WITH FLAT-BEAMS

The FB is represented by construction of a reinforced concrete building composed of two frames and multi-story bearing walls, where the longitudinal-direction is provided with Wall-columns and Flat-beams (Fig. 1.1). On this occasion, "Wall-columns" mean tall columns length, and "Flat-beams" mean short beams length and wide beams width.

The main use of the FB is for apartment houses. The Flat-beams of the FB are short and beam width is 2~3 times wider than Wall-column width. This means that the projection towards inside dwelling room is practically small. Moreover, the in the longitudinal direction is possible to construct 2 planes of structure. And the Wall-columns with small openings are possible to provided, the connection with piping arrangements and installs exhaust opening. Such being the case, the FB can secure a large opening up to the ceiling section. As a result, bright, fine venting, flexibility in floor plan, interior design, as well as variable apartment houses can be afforded successfully. The image of apartment houses constructed by the FB is shown in Fig.1.2.

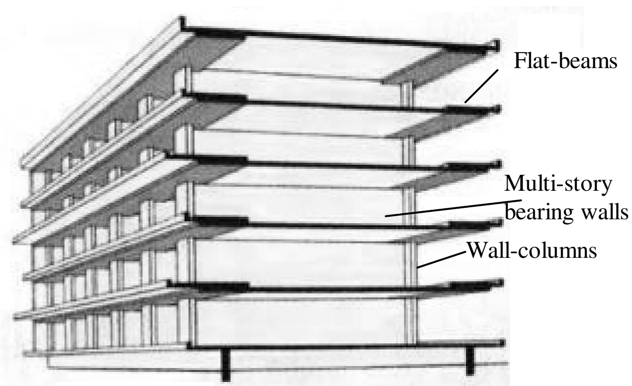


Fig. 1.1 a) Outline of FB-structure

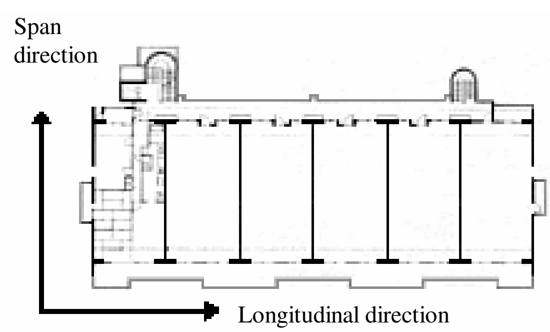


Fig. 1.1 b) Typical Plan of FB-structure

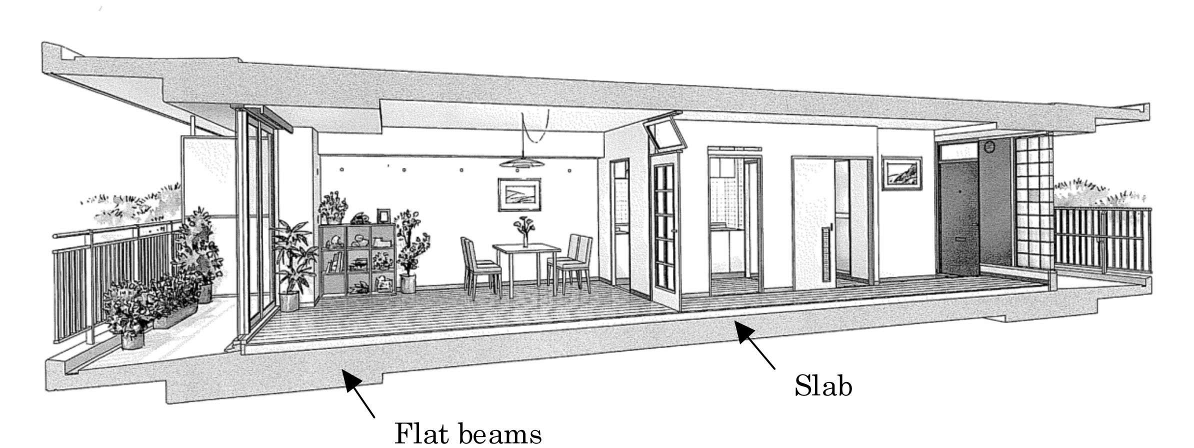


Fig. 1.2 Image of apartment houses by FB-structure

FB-GUIDELINE AND METHOD OF SEISMIC DESIGN

Outline of FB-Guideline

The FB-Guideline is engineering documents used for designing FB Structures constructed by the UDC. In the FB-Guideline, concrete structural designing method and seismic designing method are specified so as to reflect the study results, and so as to standardize the FB target structural performance, as well as so as to popularize the FB-Guideline extensively. The configuration of the FB-Guideline is shown in Fig. 2.1. According to the FB Structure Guidance, the respective Chapters contain the applicable items as shown below: Chapter 1: The Scope of Application of the Plane and Elevation Shapes of FB. Chapter 2: Target of Structural Performance required for Designing, and the Method of Structural Designing. Chapter 3: Quality and Classification of Materials to be used for the FB. Chapter 4: Combination of Loading with External Forces used for Structural Designing, as well as Seismic Forces required for Seismic Design. Chapter 5 & 6: Shape of Cross-section of Members used for the Designing of FB Structure and the Setting Method of Bar Arrangement. Chapter 7: Analysis Methods, Seismic Design and Calculation Methods used for FB, as well as also Calculation Method so as to calculate Forces generated from the respective Members by Seismic Forces. Chapter 8 ~ 10: Confirmation Method on Seismic Designing Results. In other words, How to make sure the Strength and Ductility Capacity generated in the Applicable Members calculated in Chapter 7 above. Chapter 11: Bar Arrangement Instruction on the Applicable Members.

Contents of Chapters;

Chapter 1 Scope of Application
Chapter 2 Guidance of Structural Design
Chapter 3 Quality and Classification of Materials to be Used
Chapter 4 Loading and External Forces
Chapter 5 Structure of Main Members
Chapter 6 Setting of Cross-section
Chapter 7 Methods of Force and Deformation Analysis
Chapter 8 Confirmation of Working Limit Designing
Chapter 9 Confirmation of Damage Limited Design
Chapter 10 Confirmation of Safety Design
Chapter 11 Bar Arrangement Instruction

Fig. 2.1 Contents in Chapter of FB-Guideline

Flow of Seismic Designing

In the course of the FB Seismic designing, the "Response limit strength calculation method" is used so as to verify the earthquake motions [1]. Also, in the course of Seismic designing, the following items shall be procured:

・Amplification characteristics of surface-layer soils shallower than the engineering foundation obtained from the acceleration response spectrum specified in the released engineering foundation.

・Building response procured from the acceleration response spectrum at the bottom of the building foundation thus procured after considering the characteristics, and the interaction among buildings and surface soils. The above configuration is shown in Fig. 2.2 below. For the "Yield strength -Deformation curve" which represents the structural characteristics FB Building (hereinafter called S_a-S_d line curve) and for the earthquake motions at construction site by overlaying

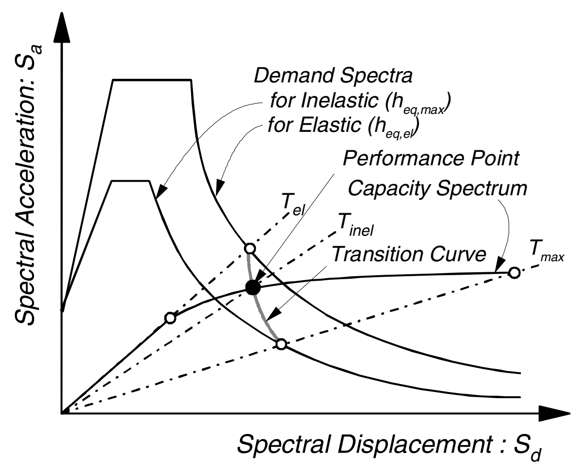


Fig. 2.2 Response point of S_a-S_d curve

the “Demand Spectrum” considering “Equivalent viscous dumping constant” in proportion to the ductility deformation amount in the FB Building, the ” Performance Point” of buildings may be estimated. Then make sure that the” Performance Point” does not exceed over the applicable limit values in the applicable earthquake level (damage limited design and safety design) determined by the material characteristics and member cross-section characteristics. The earthquake motion level, target performance and confirmed items in seismic designing are shown in Tab. 2.1, and Seismic Evaluation Procedure is shown in Fig. 2.3.

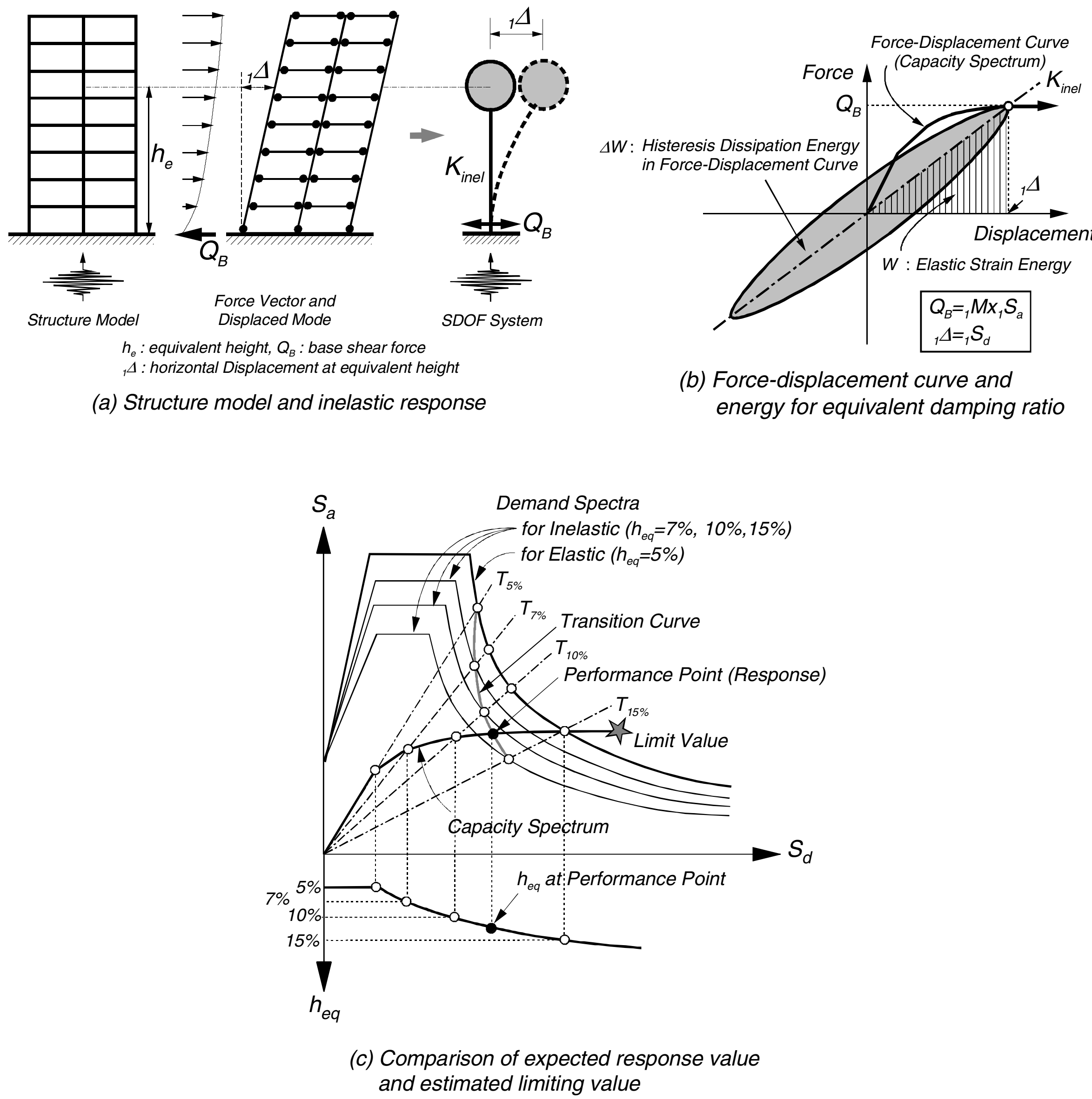
Tab. 2.3 Performance levels for buildings and earthquake motion levels

Performance Levels	Earthquake Motions	Check Items	
(a) *Life Safety* (to prevent failure of stories in structural frames)	*Maximum Earthquake* to be considered (earthquake records, seismic and geologic tectonic structures, active faults, etc.)	Response Value	Maximum Internal Force/Displacement
		Limiting Value	Limiting Strength/Displacement[*1]
(b) *Damage Limitation* (to prevent damage to structural frames, members, interior and exterior finishing materials in order to avoid the conditions not satisfying the requirement (a) and others)	*Once-in-a-lifetime Event* (return period: 30-50 years)	Response Value	Internal Force/Displacement taking place at each structural element
		Limiting Value	Limiting Strength/Displacement[*2]

Notes: *1 - Repeating cycle’s effect at plastic region of response to be taken into account.

*2 - The whole building structure behaves roughly within elastic range.

1) The limiting values corresponding to Maximum Event Level are determined based on the condition that equilibrium of forces and displacement compatibility in the structural system are guaranteed.
2) Displacement and acceleration related limiting values, determined on the basis of the requirements for architectural, mechanical and electrical elements permanently attached to building structures, are thought to be considered in certain cases.
3) The deterioration of materials during the lifetime of a structure should be considered.



(a) Structure model and inelastic response

(b) Force-displacement curve and energy for equivalent damping ratio

(c) Comparison of expected response value and estimated limiting value

Fig. 2.2 Illustration of Seismic Evaluation Procedure

The performance evaluation shall be executed in accordance with the following steps.

(1) Confirm the scope of application of the evaluation procedures and the mechanical characteristics of materials and/or members to be used in a building.

(2) Determine the response spectra to be used in the evaluation procedures.

a) For a given standard design spectrum at the engineering bedrock level, draw up the free-field site-dependent acceleration, S_a , and displacement response spectra, S_d , for different damping levels.

b) In the estimation of free-field site-dependent acceleration and displacement response (step a) above), consider the strain-dependent soil deposit characteristics.

c) If needed, present graphically the relation of $S_a - S_d$ for different damping levels (Fig. 2.2c).
(3) Determine the hysteretic characteristic, equivalent stiffness and equivalent damping ratio of the building.
a) Model the building as an ESDOF system and establish its force-displacement relationships (Fig. 2.2a).
b) The soil-structure interaction effects should be considered.
c) Determine the equivalent damping ratio on the basis of viscous damping ratio, hysteretic dissipation energy and elastic strain energy of the building (Fig. 2.2b).
d) If the torsional vibration effects are predominant in the building, these effects should be considered when establishing the force-displacement relationship of the ESDOF system.
(4) Determine the limiting strength and displacement of the building corresponding to the ESDOF system. Determine the equivalent stiffness in accordance with the limiting values, if needed.
(5) Examine the safety of the building. In this final step, it is verified whether the response values predicted on the basis of the response spectra determined by step (2) and the force-displacement relationship of the ESDOF system of the building given by step (3) satisfy the condition of being smaller than the limiting values estimated on the basis of step (4)(Fig. 2.2c).

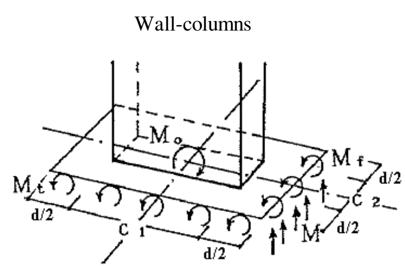
PERFORMANCE OF MEMBERS, AND OF JOINT SECTIONS OF WALL-COLUMNS WITH FLAT-BEAMS

The study of the FB was made by exercising structural experiment and analysis on the applicable members, and then, their structural performances have been grasped, as well as, the FB have been verified. In this section, the Performance of Members and of Joint Sections of Wall-columns with Flat-beams will be reported.

Performance of joint sections of Wall-columns with Flat-beams

In the FB , the joint section of longitudinal direction is composed of Wall-columns and Flat-beams. Most parts of Flat-beams, main reinforcements are not arranged inside the Wall-columns, but arranged outside the main reinforcements of Wall-columns. Moreover, around the Top of Wall-columns, it is required to consider the measures against the brittle failure (punching failure). Therefore, in order to grasp the structural performance by sustained loading and earthquake load experiment was conducted. The assumed moment M_o transfer mechanism, when seismic force was applied to the joint section of Wall-columns with Flat-beams is as shown Fig.3.1. This transfer mechanism is presumable, where Flat-beams caused respectively shearing-force moment "M_s", bending moment "M_f" and torsion moment "M_t" are considered ［2］.

For FLT100, it is a RC Specimen of which is 1/2 scale. The purpose of the Specimen FLT100 is to examine the mass of torsion resistance "M_t" in the joint section of Wall-columns with Flat-beams while horizontal loading is being applied. Therefore, in order to eliminate the influence exerted upon the bending moment "M_f" and shearing-force moment "M_s", a slit is provided on the one



$$M_0 = M_s + M_f + M_t \text{，} M_s = \tau_u (c_2 + d) d (c_1 + d)$$

$$M_f = 0.9 a_{0t} \sigma_y d (c_2 + d) \frac{1}{x_t} + 0.9 a_{ob} \sigma_y d (c_2 + d) \frac{1}{x_b}$$

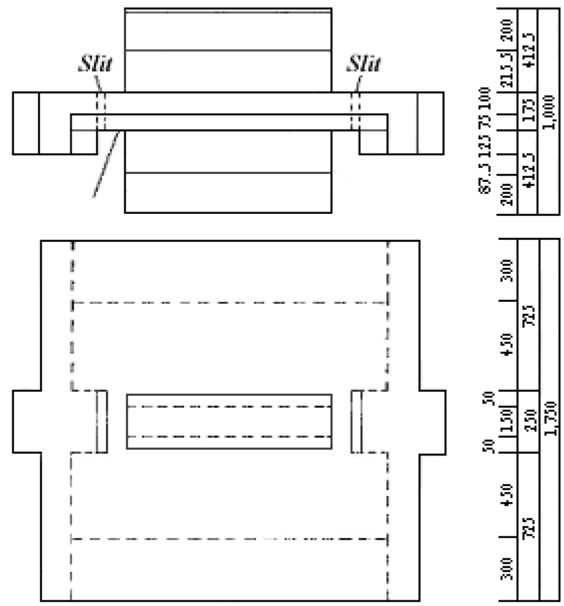
$$M_t = \tau_{tu} \frac{d^2}{2} \left\{ (c_1 + d) - \frac{d}{3} \right\} \times 2$$

$$\tau_u = 1.06 \sqrt{\sigma_B} \text{，} \tau_{tu} = 6 \times 1.06 \sqrt{\sigma_B} \text{，} V_0 = \tau_u A_c \text{，} A_c = 2d (c_1 + c_2 + 2d)$$

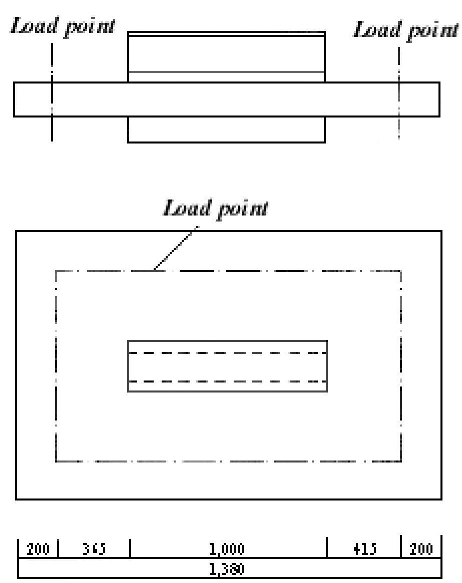
Here: σ_B *: Strength of concrete,* c_1 *: Wall-column depth,* c_2 *: Wall-column width,* d *: Effective depth of Flat-beams,* a_{ot} *: Sectional area of one Top-reinforcement,* a_{0b} *: Sectional area of one Bottom-reinforcement,* x_t *: Spacing of Top-reinforcement,* x_b *: Spacing of Bottom-reinforcement,* σ_y *: Yield strength of reinforcement*

Fig. 3.1 Assumed moment transfer mechanism in the joint section of Wall-columns with Flat-beams

part of the Flat-beams. Moreover, FLT100 is designed to make brittle failure around the joint section of Flat-beams and Wall-columns. In addition, each member Flat-beams and Wall-columns are designed to make bending failure. Other one, this specimen is FLV100. The purpose of this Specimen is to examine the punching strength"V_0" in the joint section of Flat-beams with Wall-columns. FLV100 has given load along vertical under the experiment of vertical loading [2] . For the FLV100, in the same way as the FLT100, the specifications of specimen dimensions and bar arrangement are the same, however a slit is not provided on the beams. The outline of the respective Specimens is shown in Fig.3.2. The bar Arrangement and properties of materials are shown respectively in Tab.3.1, Tab.3.2. For the FLT100, a monotonically increasing load test was conducted. According to this experiment, the Flat-beams end was load in reverse symmetrically in the vertical direction. For the FLV100, loads were applied vertically along Wall-column. FLT100, the relationship of load-deformation is shown in Fig.3.3. The yield strength of the FLT100 is 26.7ton・m adjacent to "+1/630rad". The reduction of the yield strength is approx. 80% of the yield strength in adjacent to "1/110rad.". The calculated value of the yield strength "M_t" was allowed to be approx. 0.94 time of approximate value. Moreover, the failure has been caused by the torsion resistance in the joint section of Flat-beams with Wall-columns. The failure area was generated along the Wall-columns, which were each length of effective 1/2 slab height from the surfaces of Wall-column. This means the torsion resistance moment in the joint section of Wall-columns with Flat-beams was presumed as "$\tau_{tu}=6\times 1.06\sqrt{\sigma_B}$ (σ_B= Strength of concrete), and then, this is presumable by means of procured 100% ductility torsion resistance expression "$M_t=\tau_{tu}=d2/2\ \{(c1+d)d/3\}$ ". The results of experiments is shown in Fig.3.4. On this occasion the yield strength is shown at the vertical loading "P=81.9ton(δ =10.8mm)". The punching and shearing strength at "$\tau u=6\times 1.06\sqrt{\sigma_B}$" was 1.12 times larger than the calculated value, which assumed each length of effective 1/2 slab height from the surfaces of Wall-column. After showing the yield strength, the yield strength was reduced down to "P=65ton (approx. 80% of the yield strength), and then, the yield strength can be maintained at adjacent to the vertical deformation "(δ) =18mm". On this occasion, the results of examination conducted by using the specimens are shown on the Tab.3.3 as a whole.



(FLT100)



(FLV100)

Fig3.2 Outline of specimens

Tab. 3.1 Bar arrangement (FLT100, FLV100)

Members	Main reinforcement (Pg %)	Shear Reinforcement	Slab bar arrangement
Flat-beams	D19@50 (3.83%)	6-10@200	D10@200
Wall-columns	2-D19 (3.39%)	2-D13@50	

Table 3.2 Properties of materials

Concrete		Reinforcement				
Young's modulus (×10^4 N/mm^2)	Compression strength (N/mm^5)	Deformation bar	Young's modulus (×10^5 N/mm^2)	Yield point (×10^5 N/mm^2)	Tension strength (N/mm^5)	Strain at yield point (×10^{-3})
2.02	25.2	D10 D13 D19	1.78 1.75 1.69	385 384 377	537 575 575	2.17 2.23 2.25

※ The compression strength is the test results during experiment（six weeks）

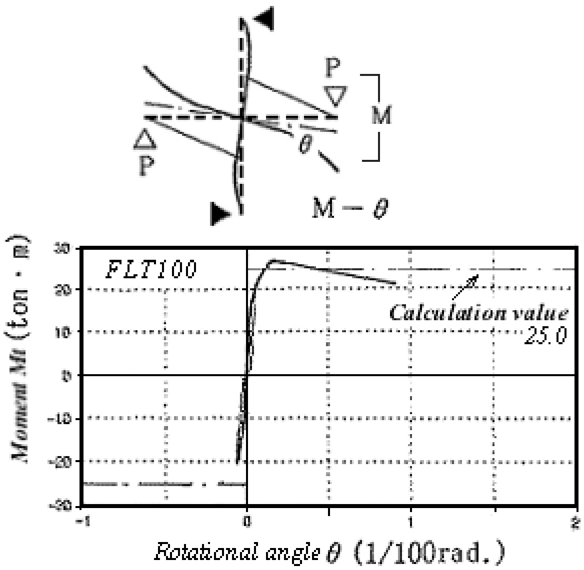


Fig. 3.3 Moment – Rotational angle relationship (FLT100)

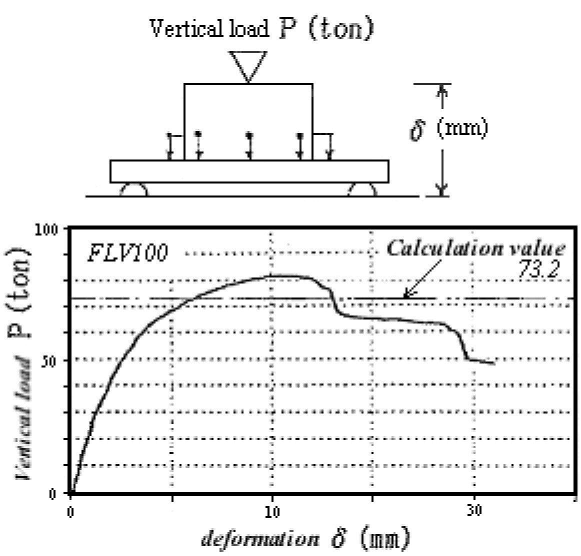


Fig. 3.4 Vertical load-Vertical deformation relationship (FLV100)

Tab. 3.3 Results of experimental

Name of Specimens	Initial rigidity *1 (ton・m)	Flat-beams at the occurrence of Initial cracking/fissure*2		Yield strength2	
FLT100	8.23×10^4	7.49	-6.96	26.66	-
		0.10	-0.10	1.58	-
FLV100	occurrence of initial cracking/fissure：39.9ton				
	Yield strength：73.2ton				

*1 The ratio between the Moment M acting on the joint section of Flat-beams and Wall-columns, and rotating angle “ θ ” against the Flat-beams of the Wall-columns.

*2 Upper stage：Moment M acting of the Wall-columns（ton・m.）
Lower stage：Rotating angle “ θ ” against the Flat-beams （×1/1000 red.）

Performance of Wall-columns provided with Small Opening

FB is featured by the installation of plural numbers of small openings on the Wall-columns. These small openings are used for air-conditioners, ventilations and the other pipes. But, in proportion to the creating of high-rise building, Wall-columns will be keeping large the axial force. Therefore, it will be required to grasp the ultimate yield strength and deformation performance, and then, repeated horizontal monotonically increasing load experiment was thus conducted on the RC specimens ［3］. The outline of the Specimens is shown in Fig. 3.5 and on Tab.3.4 respectively. On this occasion, the specified design strength on applied concrete is “27N/mm^2”. In fact, the FLB000 is so designed that the bending failure may take the precedence over others. In the same way, the FLS000 is so designed that the shearing failure may take the precedence over others. Both Specimens are not considered as the reduction of ultimate strength caused by providing small openings.

The Relationship of between Load and Deformation is shown in Fig.3.5. For the FLS000, it had excess strength of approx. 1.3 times in proportion to the calculated value of the shearing ultimate strength. In addition, in all specimens, the cracking width after removing the loading stress experienced in square members, 1/100 was less than 0.1mm, which is actually less than the cracking width ; 0.3 mm required for repair. Moreover, the influence exerted upon cracking width caused by the small openings is less. In fact, up to the deformation of 1/30, remarkable propagation of cracks and collapse up to the deformation were not observed around the small openings.

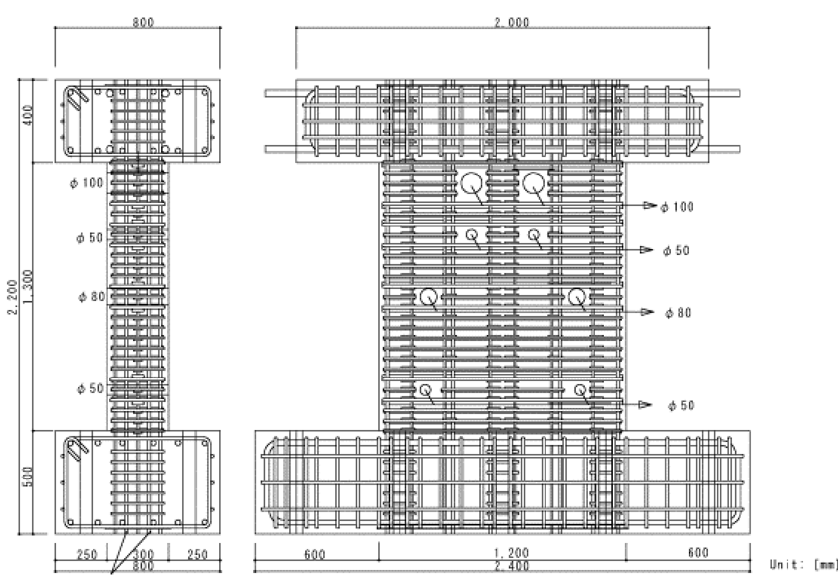


***Fig. 3.5 The reinforcement bar arrangement of test* specimens (FLB000, FLS000)**

Tab. 3.4 Details of specimens

Name of Specimens	Wall-columns width(mm)	Wall-columns depth(mm)	Main reinforcement	Sear reinforcement
FLB000	300	1,200	3-D13 (Effective tension reinforce bar) 16-D10(Intermediate reinforcement)	D10@50 D6@50 (Core reinforcement)
FLS000			5-D13(Effective tension reinforce bar) 16-D10 (Intermediate reinforcement)	

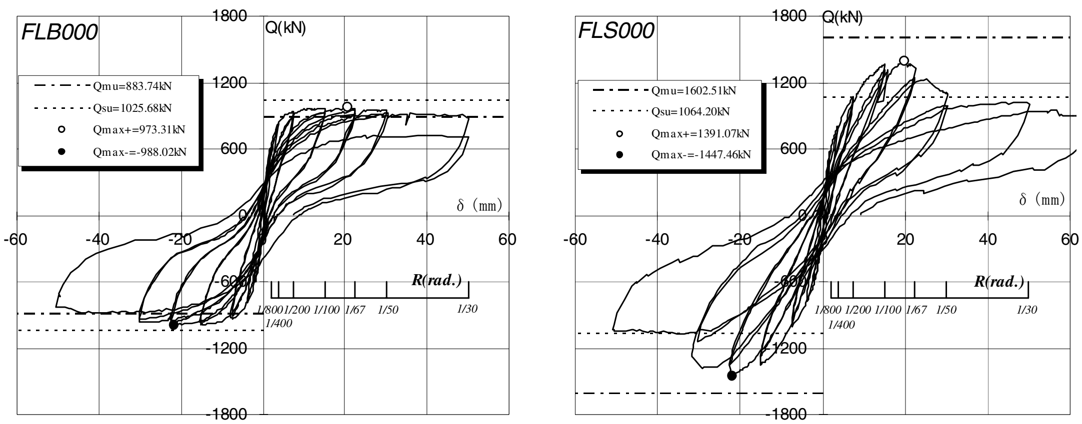


Fig. 3.6 Horizontal load –Deformation relationship

Earthquake Response Analysis

In order to grasp structural performance required for the construction of FB, this is required base shear coefficient and ductility capacity. The static monotonically increasing analysis and the earthquake response analysis were conducted of the typical frame. The outline of analytical model and specifications for the earthquake response analysis are shown in Fig. 3.7 and Tab.3.5. As the specifications of materials used for analysis : Specified design strength of concrete was set to 24(N/mm^2),Young's modulus, and shearing elastic coefficient were set to 2.1×10^4 (N/mm^2), and 0.913×10^4 (N/mm^2) respectively. In the same way, the Young's modulus, strength of main reinforcement and strength of shear reinforcement were set to 2.1×10^5 (N/mm^2), 400 (N/mm^2) and 300(N/mm^2) respectively.

In the evaluation of the elastic rigidity of Flat-beams, the effective width of Flat-beams was thought to be square cross-section of (2t+b) cm, where, t = Flat-beam height (mm), b = wall width (mm). In the earthquake response analysis, the damping ratio was 2％ in the primary vibration mode, and was frequency proportional type in the high vibration mode. As input three earthquake waves have been EL CENTRO NS (1940), TAFT EW

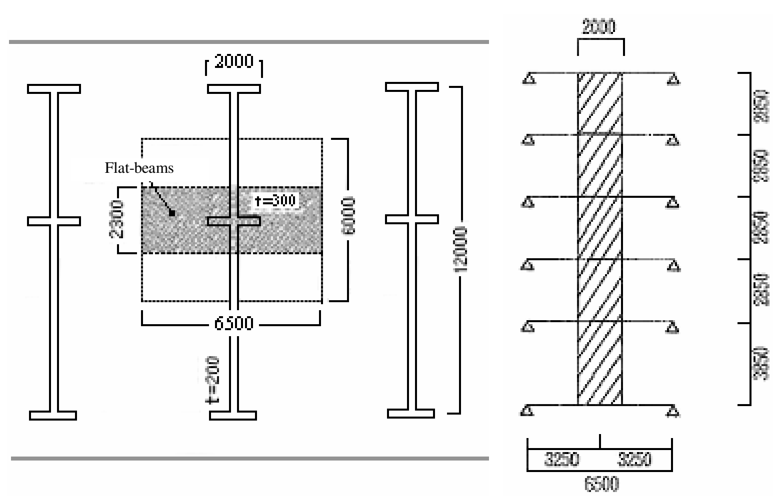


Fig3.7 Outline of analysis model

(1952) and HACHINOHE EW (1968). Then, the applicable maximum acceleration was set to 200 gal and 400 gal respectively.

Tab. 3.5 Specifications of analysis model

Story	Weight (ton)	Story height (mm)	Wall-columns width (mm)	Flat-beams width (mm)	Height of Flat-beams(mm)
5 -Story	35.3	2,850	300	2,300	
4 - Story	39.2	2,850	300	2,300	350
3 - Story	39.2	2,850	300	2,300	
2 - Story	39.2	2,850	300	2,300	
1 - Story	39.2	3,850	300	2,300	
Footing beam	-	-	-	450	2,000

Tab. 3.6 Setting of restoration strength characteristics of Wall-columns and Flat-beams

Members	Bending characteristics	Shearing characteristics
Wall-columns	・D-Tri model But, Home position orientation up to the bending yield point: bi-linier model ・Square members provided with yield strength against bending 1/1,000	・Home position orientation type, bi linear model ・Square members showing strength against crack: 1/5,000 ・Square members showing yield strength: 1/500
Flat-beams	・D-Tri model ・Square members provided with yield strength against bending 1/100	(the same as above)

The results of the static elastic and ductility at monotonically increasing load were C_B=0.417 of base shear coefficient with story deformation angle 1/192. The relationship of story shear force - story deformation obtained from the results of the static analysis and experimental of monotonically increasing load is shown in Fig. 3.7. The result of experiment is specimen FL63B, which is shown in Fig. 3.8. The axis of ordinate in Fig. 3.9 is represented by averaged story shear force after dividing by the force by the member section. For the FL63B, in order to grasp the horizontal yield strength against the joint of Wall-columns with Flat-beams, as well as in order to grasp the structural performance, in the same way as the FLT100, the FL63B is a Specimen (Fig.3.10). The reason why the experimental value is larger in comparison with the analytical results is presumable by the influence exerted on the orthogonal wall and slabs.
The results of earthquake response analysis are shown in Fig.3.11～Fig.3.12. The primary natural period of an analytical model is 0.434 sec. and the base shear coefficient according to the earthquake response analysis was 0.27 at 200 gal and 0.39 at 400 gal. The maximum response of story deformation angle is 1/260 at 200 gal, and 1/114 at,400 gal（all were EL CENTRO NS）. In addition, as the result of 400 gal response, except 1-story Wall-columns base, the result shows less than bending yielding force. Then the ductility factor at 1-story Wall-columns was 1.14, at EL CENTRO and 3.06 at HACHINOHE.
Since the FB is represented by small yield strength of Flat-beams in comparison with ordinary RC Wall-frame structure. As a result, large bending moments are applied to the 1-story Wall-columns base. Then it was understood that sufficiently strength and ductility capacity shall be provided to the 1-story Wall-

columns and foundation beams against this bending moment. According to the FB-Guideline, reflecting upon this idea, designing of Wall-columns base section has been improved, and the ductility factor has been revaluated, and then, the improved cross-section of members and bar arrangement have been set newly.

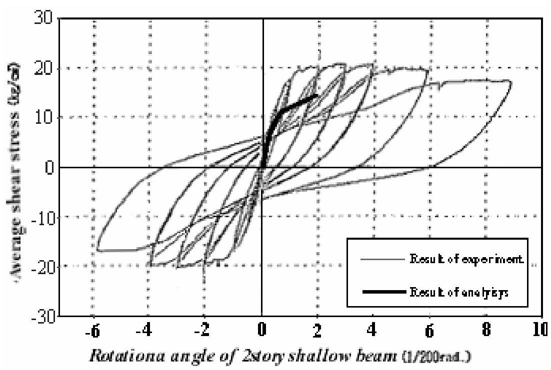


Fig3.9 Comparison between static elasto-plasticity gradual increase analysis and experiment

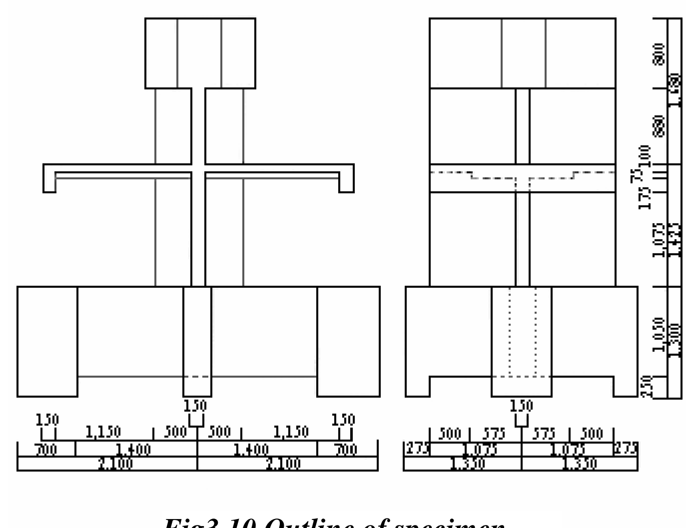


Fig3.10 Outline of specimen

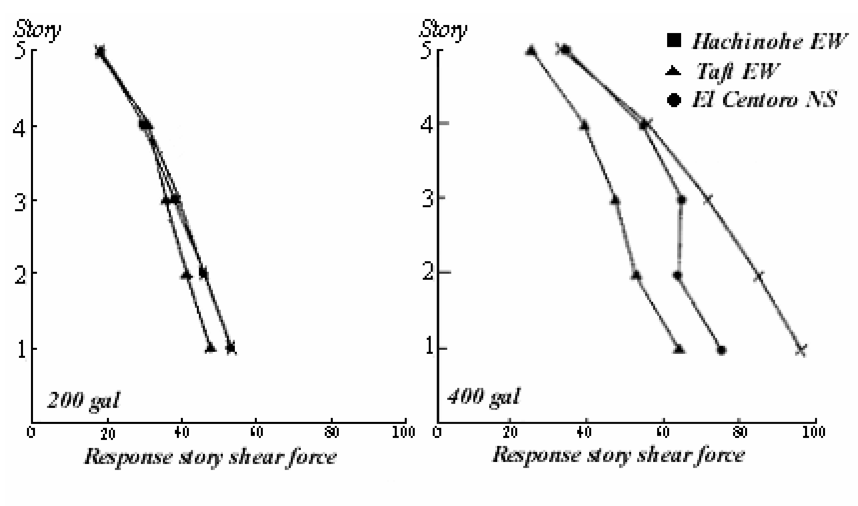


Fig. 3.11 Response of story shear force

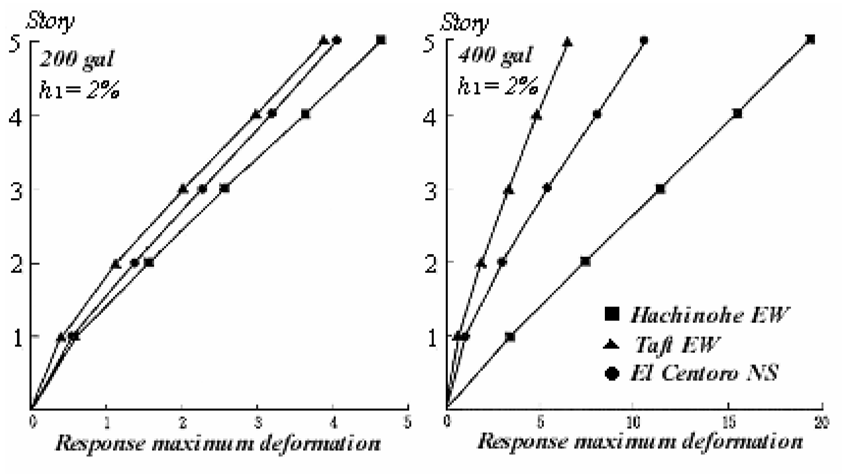


Fig.3.12 Response of story deformation

Elastic and Ductility Monotonically Increasing Analysis

In order to verify the creation of high-rise buildings in FB, as well as in order to make sure the member dimensions and section at 2-plane of structure in the longitudinal direction, "Elastic and Ductility Monotonically Increasing Analysis" was conducted on 6-span, 15-story building. The analytical specifications are shown in Tab. 3.7. The story height was 2,900 mm at 2-story ~ 15-story, and the story height of only 1-story was 4,420 mm. The rigid zone of Flat-beams was examined on 1/4D（D= Flat-beams height）from the orthogonal wall column face after considering the square cross-section. Moreover, the analytical model was transferred from both the Wall-columns and Flat-beams to the linear model, and thus, Tri-linier model was obtained. In addition, the footing beams were analyzed so that they have sufficient rigidity.

Tab. 3.7 Specifications of analysis model

Flat-beams B×D , （2,000 mm×450 mm）			Wall-columns B×D , （800 mm×2,000 mm）		
Specified design strength of concrete (N/mm^2)	Main reinforcement	Shear reinforcement	Specified design strength of concrete (N/mm^2)	Main reinforcement	Shear reinforcement
［RF～13F］ 30 ［12F～9F］ 33 ［8F～2F］ 36	［RF～8F］ 16-D29	6-D13@100	［15F～12F］ 30 ［11F～8F］ 33 ［7F～1F］ 36	12-D29	4-D13@100
	［7F～2F］ 17-D29				
	［1F］ 18-D29				

Stories enclosed by ［ ］ show FB-model stories.

As the result of analysis, at period when the maximum story deformation angle is approx. 1/30（At the period of × shown in Fig. 3.13）bending yield dose not occur except 1-story of Wall-columns base and Wall-columns applied tension force. On this occasion the base shear coefficient in each story is approx. 0.31. This means that there is sufficient strong yield strength. Such being the case, according to the member dimensions used this analysis provided with sufficient allowance in the bar arrangement, the designing of 15-story FB building will be sufficiently feasible. As a results, the FB-Guideline, less than 11-story and the height is less than 40m spec. that is set up within the scope of application for the FB.

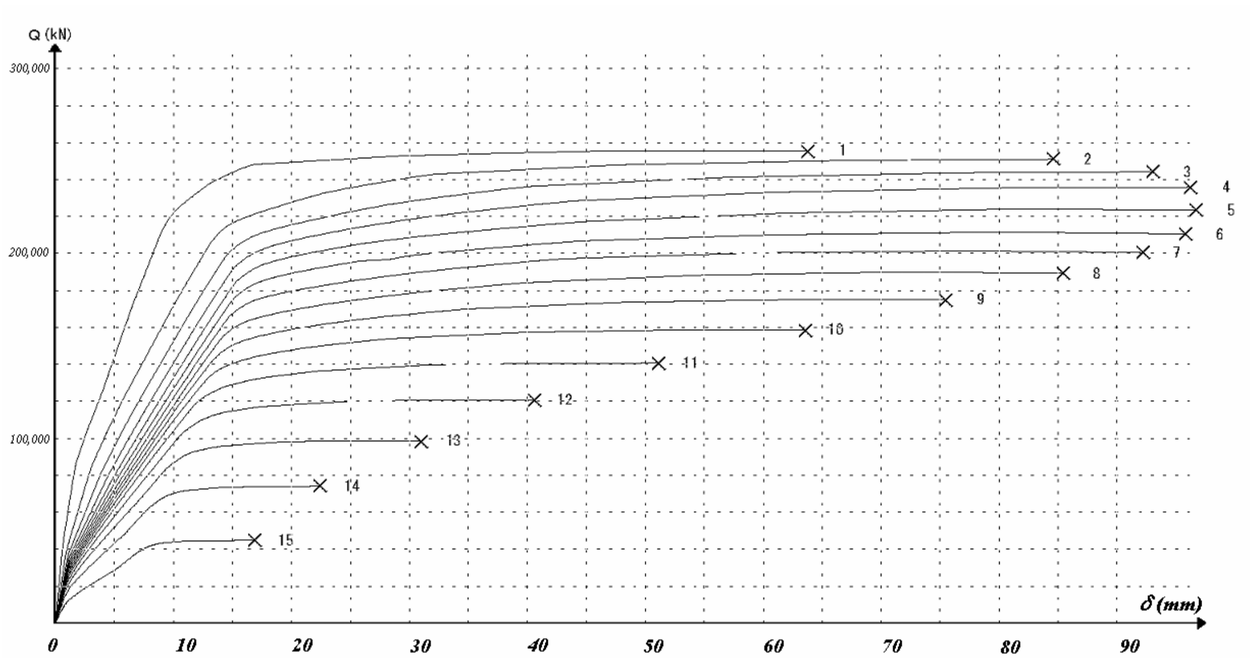
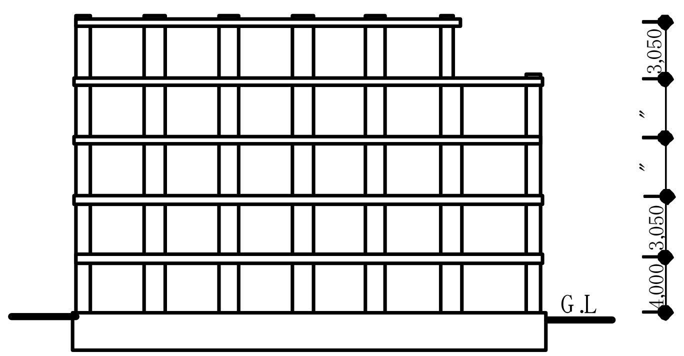


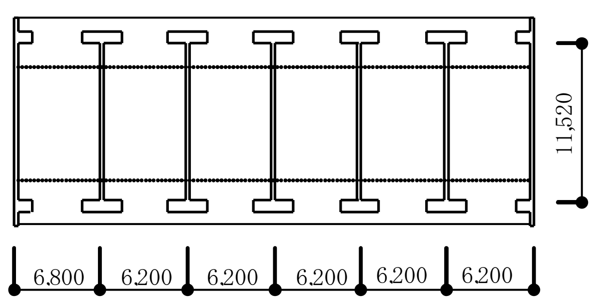
Fig. 3.13 Story shear force-Story deformation relationship

INTRODUCTION OF EXAMPLES

The outline of FB Buildings constructed by UDC is shown in Fig. 4.1～Fig. 4.2. This FB has been designed for 5-story apartment houses.
As a result of the seismic design, the maximum story deformation angle in the longitudinal direction was approx 1/500 at damage limited design and was approx 1/70 at safety design. The outline of the results of seismic design is shown in Tab. 4.1.



a) Elevation outline



b) Plane outline

Fig. 4.1 Outline of FB Buildings

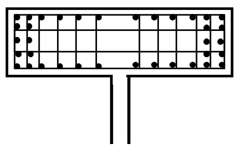
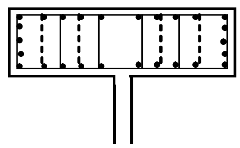
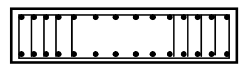
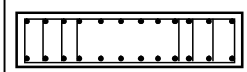
	1F Wall-Columns (Bottom)	5F Wall-columns	2F Flat beams	RF Flat beams
Section				
B×D	2,000×500	2,000×500	2,000×400	2,000×400
Main Reinforcement	24-D29+16-D25	10-D29+16-D19	8-D29+6-D22	6-D29+6-D22
Shear Reinforcement	目-S12.6@100	口-D13@100	目-D136@125	目-D13@125

Fig. 4.2Outline of member section (Wall-columns, Flat-beams)

Tab.4.1 Outline of Seismic Design results

		Damage limited design	Safety limit design
Equivalent period (S)		0.489	0.943
Base Shear of 1-Story		0.26	0.56
Damping Ratio (%)		5.0	17.0
Story shear Rotational Angle	5- Story	1/600	1/70
	4- Story	1/543	1/69
	3- Story	1/519	1/70
	2- Story	1/563	1/74
	1- Story	1/1230	1/135

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