RECENT USE OF CONCRETE IN SMALL AND MEDIUM-SCALE JAPANESE BUILDING PROJECTS

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INTRODUCTION

This paper describes several actual concrete buildings in Japan designed by the Author and his practice. They are all either individual houses or small condominiums and offices. The use of as-cast concrete in such projects is quite common in Japan, presenting the engineer with many opportunities for structural innovation and expression. The projects introduced here have been chosen to illustrate some of these possibilities. Special attention is paid to the relationship between the structural and spatial design in each. In particular the attempts made in each to unify structural and functional aspects are investigated.

HOUSE IN TOKYO, SANGENJAYA, TOKYO

A response to a typical house-planning problem in Tokyo, the house attempts to provide high-quality accommodation and car parking for a three-generation family on a confined site. In this case the site dimensions were only 10x4.3m, and a house was required for a couple, their parents, and future children. The budget was also tight by Japanese standards at about 230,000 US dollars.

A four-story structure was proposed to optimize floor area within cost and height limits (Figure 1). Half of the ground floor is used as a garage, the other half as the parents’ bedroom. The parents’ living space is on the second level. This leaves the upper two floors for use by the young family. It was agreed with the client that a ‘no-frills’ building would be provided, leaving refinements for a future date when funds became available. Even wall insulation was left out of the design to save money.

Maximum use was made of the external walls as shear planes to resist seismic loads. The strength of concrete in shear meant that these could be made very thin (150mm in the upper two levels) maximizing the internal space.

The removal of shear walls on the open street facade was achieved by including a local thickening of the walls and slabs to 300mm to form a moment frame (Figure 2). Although the sway stiffness of this frame was much less than that of the shear wall gable on the rear facade, we were able to show by analysis that sway deflections of the front facade would be less than 1/200 of each story height. This was accepted by the local authority (Figure 3).

Figure 1: General view
The other unusual structural feature in this house is the framing used in the east facade. The large cruciform opening overlooking a small park was achieved by including a cranked beam within the roof parapet, and by suspending the fourth level slab using walls in tension (Figure 4/5).

Slab loads are carried by the east facade fourth level walls up to the cranked beam and distributed into the walls on either side of the cruciform opening.

This action can also be visualized as a form of arch spanning over the cruciform opening.

The result was great transparency in this facade, allowing views over the park and surrounding cityscape (Figure 6).

**HOUSE IN HODOGAYA (II), YOKOHAMA**

The house is constructed on a triangular site located at the junction between two residential streets. The site level is elevated by about 1.3m above the bordering road levels. In order to accommodate a car park the architect proposed to make a cutting across the site down to the level of the roads. The house proper would then be constructed above this cutting (Figure 7).
The retaining walls and base slab to this cutting are formed in concrete. The second level slab is supported from the tops of the retaining walls. In order to provide sufficient headroom in the car park however, the second floor slab was raised by about 900mm above the wall tops by casting vertical and diagonal struts into the wall tops and slab periphery beams. The struts are formed from 65x30mm solid stainless steel sections. The number of diagonal struts was kept to the minimum required for transfer of horizontal loads (Figure 8).

Once complete the second level slab formed a base for the two-story timber panel structure above. This was constructed using stressed-skin plywood panels to transfer horizontal loads.

The house is thus a hybrid - RC and stainless steel lower structure, and timber superstructure. Apart from cost considerations, the use of timber for the upper half reduced weight and therefore seismic loads acting on the stainless steel connecting struts (Figure 9).

This is another house designed with the architect Hideyuki Yamashita. Like the House in Tokyo, the low budget (170,000 US dollars for 100m²) allowed the construction only of a simple two-story concrete box.
The south façade faces onto a small garden. Yamashita's scheme proposed opening this side of the box on both levels as far as possible. It was decided to brace this façade using two large V-braces extending over the full height. These members carry both seismic loads and the permanent loads from the roof and cantilevered terrace on the second level (Figure 11).

The distinctness of each element was an essential part of the spatial experience in this house (Figure 12). The braces in particular cut through the volume to lend a strong dynamic, which is heightened by the play of light and shadow through the south façade. The visual tones produced on the concrete surfaces work all the better for the as-cast finish on all the elements.

The generally good as-cast quality achieved by Japanese contractors was obviously very important in this project. The chance to collaborate with them on points of construction detail also improved the overall result. Careful planning of the positions for through ties served to reinforce the directionality of the braces relative to the walls for example (Figure 13).

The same braces are provided on the north elevation, but here single-layer reinforced concrete infill walls are added to close off the elevation. 180mm thick gable walls at each end carry sway loads in the short direction.

An effort was made to make sure that each structural element was simple with a clear function. We were also careful to make sure that each was kept to a realistic minimum dimension - the V-braces are 450x200mm in section, the second level slab (which cantilevers 1.8m over point supports) 230mm in thickness.

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The ORANGE FLAT APARTMENTS, SENDAI

This building, known as Orange Flat, is located in a suburb of Sendai. It was planned as a low-cost block of rented apartments. Thirty units each of about 52m² floor area are accommodated (Figure 14). The architect decided to arrange the units in two separate three-story blocks of fifteen units each separated by a 10 metre wide courtyard. The two sides were to be joined by bridges which would also link with central staircases for vertical access.

Rather than employing the frequently used moment frame system, a scheme which made full use of the wall elements to resist horizontal force was developed. Moment frames tend to require rather
heavy beams and columns in Japan, and in this case the architect wanted to keep the outer facades of the building as open as possible. By locating shear walls along the inner facades on each side of the courtyard and between the apartment units, it was hoped that the outer facades could be kept relatively open. As a further effort toward transparency, flat-slab construction was chosen. Columns were designed to carry only vertical loads and could thus be made of minimal dimension (Figure 15).

When considering the effectiveness of this initial scheme to seismic loading it was soon realized that significant bending moments could develop at the ends of the connecting bridges if they were rigidly connected to the slabs in the event of unequal horizontal loading on each of the buildings in the longitudinal direction. If the bridges were articulated to prevent transmission of force between the buildings however, the structures would behave independently with very large eccentricity in shear wall distribution in the longitudinal direction.

As an alternative, a diagonal system of bridges connecting the two buildings was developed. The two sides were shifted by one grid relative to one another to form a horizontal truss. This proposal was considered and accepted by the architect. Apart from the structural merit of linking the slab on either side rigidly, the scheme also offered the advantage of interconnecting all of the apartments on any level, effectively producing a single access deck at each level. As a result the number of access/emergency stairs could be reduced from three to two (Figure 16/17)

The architect had developed an initial scheme comprising two mirrored buildings linked by three perpendicular bridges. As an important conceptual aspect of this scheme, she wished to express as far as possible the continuity of the slabs on either side of the courtyard. One of the other main architectural aims was to maintain openness in all facades not facing onto the courtyard. The shear wall elements were therefore located along the courtyard facades and perpendicular to this between each apartment unit to serve also as party walls.

The structure was analyzed using Japanese commercial frame analysis software. A wire-frame model was used with the shear stiffness of wall and slab elements modelled as equivalent brace members. No guidance was available in current Japanese codes on the pattern loading cases which should be considered when designing such cross-linked buildings. After consultation with the Ministry of Construction, it was decided to consider for the seismic load case a scenario where the live load in one block of the structure is reduced by 50% while full earthquake live load is applied to the other.
block. The uneven distribution of load is the case for which the cross-linking can be expected to be most effective in comparison with a perpendicular connection scheme.

Floor and roof slabs are supported on columns and walls on a 4.4m x 3.8m grid. 1.6m and 1.0m cantilevers are used on the perimeter facades to support balconies. 180mm thick slabs are used throughout. Reinforcement was generally D10 bars at 250 centres or 150 centres within 1m wide beam strips over column lines and walls.

The four diagonal bridges forming the horizontal trusses on the second and third levels are aligned at approximately 45 degrees and span approximately 10.7m onto corbel brackets cantilevered from the party wall lines. The bridge ends are structurally continuous with these bridges brackets which results in torsional moment transfer into them. Significant torsion is only developed in the end bridge brackets; in other locations the end torsion from bridges on either side of the bracket roughly cancel each other.

![Figure 18: Detail of bridge soffit and support](image)

220mm thick shear walls are used in the party wall locations. The thickness is increased to 260mm for the gable walls since these only occupy one bay on the upper two floors.

260mm square section columns were used throughout. These were sized on consideration of the maximum axial loads at ground floor level, and the effect of bending in the top storey columns (since the roof level is not cross-connected significant torsion arises on each side under longitudinal earthquake loading producing bending in the columns).

**OFFICE BUILDING, KITA WARD, TOKYO**

Located on a small triangular site close to an expressway, this building is typical of small office development projects in Tokyo (Figure 19) The owner required living accommodation located over rentable office space and parking. In this case there are three residential floors over two office, with the ground level given over to parking and public space.

It was decided from an early stage to open up the structure at ground level in order to allow the development to perform a better urban role in terms of public use of the corner. This seemed best achieved by using a large RC cylinder column to support most of the loads from above. Access to the office space is gained via a spiral stair within the column.
The relatively small scale of the floor plates above meant that each could be supported economically using perimeter columns. These in turn are supported on the perimeter of the second level slab which is progressively thickened radially towards the cylinder column to allow adequate cantilever action.

Figure 19: Site viewed from above

Various arrangements were explored for the perimeter columns. A semi-random system of inclined concrete columns was developed. These approach triangulation at several nodes but never line-up to give a traditional truss structure. The degree of eccentricity was controlled to prevent excessive bending moments in the slab edges while also providing adequate support around each perimeter (Figure 20).

Figure 20: Structural model

In order to accurately assess the stresses developed in this rather complex frame, a finite element analysis was performed using MSC Patran software. The results were used to progressively modify dimensions of members until deflections and stresses were acceptable. The results were checked against an analysis by wire-frame modeling on other software (Figure 21).

Figure 21: Analysis model

Keeping the thickness of the column elements the same at 260mm, the width was varied as appropriate between 400 and 700mm. 33N concrete was used throughout for the superstructure elements.

The building is currently under construction.

DISCUSSION

In each of the structures described the engineer has attempted to use concrete in an efficient and economic way. Thin shear walls are an efficient method for the transfer of seismic loads, and where appropriate to the architectural scheme they have been employed. In Orange Flat the cross-linking of the slabs allowed them to be used in pure shear, and the columns in pure compression. In Tokyo House shear walls are important, but accommodation of an open facade required combination with a moment frame system.
RC shear walls were only employed in the lower structure of House in Hodogaya (II). The structural function of each element is clear however: The lower walls carry shear, the stainless steel struts axial loads, the second level slab bending on pin peripheral supports.

A mix of brace and shear wall action is used in TM House, but in this case in concrete for all elements.

The Office Building in Kita Ward uses a variety of elements to carry horizontal loads. The semi-random 'column' elements over three of the facades are an attempt to achieve a reasonably efficient bracing system which permits some degree of bending. An important aim was to increase physical and visual interest.

Efforts were made in each project to maintain clarity and integrity of the structural scheme while fully integrating this with the architectural and spatial programme. If these projects are considered aesthetically successful, then this approach may be of use in improving the beauty of our concrete structures in general.

PROJECT DETAILS


Orange Flat: architect – Itsuko Hasegawa Atelier; contractor – Ando Construction; completed – 2000

Office Building, Kita Ward: architect – Milligram Studio, Tokyo; contractor – Iwamoto Gumi; completion date – May 2004