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Some Problems in Design the Transfer Structure

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Abstract: In this report, we present the problems encountered in the design process of transfer structure in high-rise buildings in Vietnam in general and typical Dolphin plaza project. Transfer structure has been used more and more in the last ten years in Vietnam, however, there are many complicated problems when designing this type of structure such as: selecting structural solution, structural modeling, seismic resistance, construction state. For each issue, we also propose a safe and economical way to solve it.

Key words: transfer structure, reinforced concrete, structural solution, structural modelling

1. Introduction

In recent years, the development trend in architectural design of high-rise buildings is to create large space with multi-uses. The lower floors of the building are often designed to serve as service areas such as shopping centers, restaurants, and entertainment areas ... While the upper floors are often designed for office use or residential, just small or medium space. It is the division of space in the upper and lower floors of the building that requires the appearance of a transfer structures on the intermediate floors.

When a high-rise building has a big change in the column grid system between the upper and lower floors, the transfer structure will be used. Transfer structures can be steel beams, steel truss, reinforced concrete beams, pre-stressed reinforced concrete beams and often have large dimensions and weights. In terms of structure, the transfer structure is the discontinuous zone for the vertical structure, where the mass and stiffness are concentrated, so the calculation and structure for this area are much more complicated. However, because of the utility and aesthetic benefits of the structure, the transfer structure is still used more and more in the world and in Vietnam.

In the world, high-rise buildings are also widely applied in areas of low and medium earthquakes such as countries in Southeast Asia: Thailand, Malaysia, Singapore, especially Hong Kong [2] and some cities in China. According to statistics, before 2016, more than 70% of high-rise buildings in Hong Kong were designed with transfer structure. China Construction Research Institute has introduced the design and construction options for the transfer structure in high-rise buildings in Hong Kong, Shenzhen, Guangzhou and around Beijing. Some constructions use transfer structure such as Nanyang Hotel, Beijing. The building consists of 24 upper floors, with a total height of 85 m. From 1st to 4th floor, use a bearing core structure, the transfer structure is located on the 5th floor, from the 6th floor upwards, the structural wall system and bearing core.

In Vietnam, the structure of moving in high-rise buildings has developed rapidly in both size and type. In Ho Chi Minh City, the transfer structure has been used for buildings: Hung Vuong Plaza (37 floors), Saigon Pearl (39 floors), Sealing Tower (26 floors), Hanh Phuc luxury apartment (20 floors), office building in Nhon Trach, Dong Nai (17 floors). In Hanoi, there are typical projects using transfer structure:

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Ministry of Public Security, Dolphin Plaza, FLC Twin Tower, Lancaster Nui Truc, The Pride.

In this report, we present the problems encountered during the design of a transition structure in a high-rise building in Vietnam in general and take the typical example of Dolphin plaza, which is the largest project of transfer of reinforced concrete beams in Vietnam to date. There are many complex issues when designing structures of this type such as choosing structural options, analysis models, earthquake resistance calculations, construction stage calculations, etc. For each problem, we also propose a reasonable and safe.

2. Analysis of Problems in the Design and Construction of Transfer Structures

For high-rise buildings, the design and construction work are closely related to ensure the safety and economics of each project. However, with medium-sized buildings and the simple shape, there is already a classic construction process, so the design work has not changed much. For buildings that use transfer structures with large dimensions and weights, thorough analysis and a reasonable combination of design and construction are required to provide an effective solution.

2.1 Selecting Solution of Transfer Structure

Like other long span structures, transfer structures around the world often use materials with high strength and stiffness, so reinforced concrete, pre-stressed reinforced concrete or steel in the form of beams, slabs or truss structure is usually the choice. However, the selection of specific solution still depends heavily on the structural properties, construction time, capacity of contractors and product cost. It is possible to look at the transfer structure options that have been used in Vietnam in the past time as follows:

- Steel truss: Ministry of Public Security (47 - Pham Van Dong, 42 m span), VietInBank Tower (span 30 m). This type of structure is often used with very long span structures and heavy loads.
- Reinforced concrete beams: Lancaster (20-Nui Truc), Sun Ancora (3-Luong Yen), Soleil Anh Duong (Da Nang), FLC Twin Tower. This type of structure is often used to change the shape of a vertical structure from a column to a wall and with short spans.
- Prestressed concrete beams: Training Center of National Economics University, Dolphin Plaza (28-Tran Binh) [6], The Pride Hai Phat. This type of structure is also used to overcome relatively long spans.

The Dolphin Plaza project [6] is located at 28 Tran Binh-Hanoi using the following transfer system: the space under the transfer structure has 3 spans of approximately 14 m, 28 m, 14 m, used as public spaces, the space on the transfer beam is the apartment with 6-7 m spans, the transfer structure must support 25 floors (Figs. 1a, b).

In the design phase, we have come up with three solutions: two for using shaped steel truss and one for pre-stressed reinforced concrete beams (post-tension).

a) The first solution: shape steel truss with box cross-section (transfer frame), this is an option inheriting from the concept of designing classic steel truss (Fig. 2).

- + Advantages: lighter weight compared to the pre-stressed reinforced concrete beam option, large structural stiffness, high aesthetics, saving construction time at the construction site, deflection almost does not develop over time. Space should be safe for the upper structure.
- + Disadvantages: the cost is larger than the pre-stressed reinforced concrete beam project (about more than 2 times in Viet Nam), the details of joints is designed and manufactured relatively difficult, almost the entire structures is manufactured in the factory, so it must be use specialized equipment (cranes with great lift

and reach) to install, costly maintenance over time (antirust paint).

b) The second solution: Shaped steel truss with layered cross-section profiles (thickness of layer is of 40mm) are used at the Ministry of Public Security project (Fig. 3).

Fig. 1 a) Image of the building; b) Layout of transferred structure.

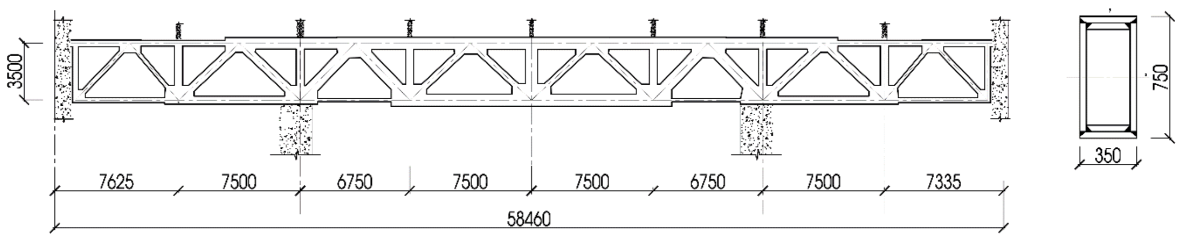

Fig. 2 The solution truss with box-bar: a) Diagram of truss; b) Cross section of typical bars.

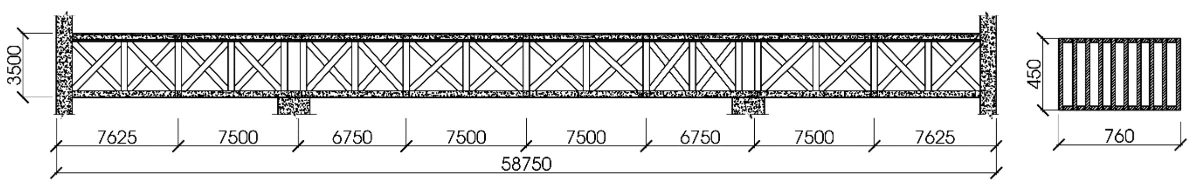

Fig. 3 The solution truss with multi layer bar: a) Diagram of truss; b) Cross section of typical bars.

- Advantages: there are also full advantages of the steel structure and fabrication is much simpler than the first solution, can be constructed on site.
- Disadvantages: the amount of material is equivalent to first solution, so the cost is quite large. If choosing the manufacturing solution at the construction site, it will take a long time (estimated 11 months) and if choosing the manufacturing solution in factory then amplifies at the site requires specialized equipment to install it.

c) The third solution: pre-stressed reinforced concrete beams (transfer beam or transfer plate), this is a method that has been used extensively in high-rise buildings in Singapore and Hong Kong.

- Advantages: the biggest advantage compared to the steel truss solutions is cost savings, in addition to the relatively fast construction time (more than 1 month), the maintenance costs over time are also not much. Take advantage of design and construction experience of experienced contractors such as VSL, Freyssinet, Ultracon, Tham & Wong.

- Disadvantages: self weight of concrete is very big so the cost of formwork and prop system is significant, the process of construction and maintenance of mass concrete is relatively complicated.

This is the option chosen because of the superior advantage of cost and construction time.

2.2 Modelling Transfer Structures in Structural Analysis [8]

Modelling transfer structures in structural analysis is also a complex problem. Detail degree of modelling depends on the properties of the transfer structure and the interaction with adjacent structures. Steel transfer truss is still the usual model. The chords and web members are modeled as frame elements at the axis and gathered at the joint. The joints are chosen as the rigid connection.

We will analyze more the following about the calculation models of transfer reinforced concrete and pre-stress concrete structure because this type of structure is used more and more. Reinforced concrete transfer structure can be modeled according to the following four types:

a) Frame element model: this type is suitable for slender beams (L/h > 5), with upper and lower elements being columns, lying in the same plane (Fig. 5a). This is the simplest type of model suitable for the analysis overall models of the building, but, it is not possible to calculate the joint areas between transfer beams and adjacent structures.

b) Plate element model: this model is suitable for long span structure (L/h > 5), with upper and lower elements being columns but not lying in the same plane, this type of structure can be called transfer plate, the internal force has two-way bending and torsion (Fig. 5b).

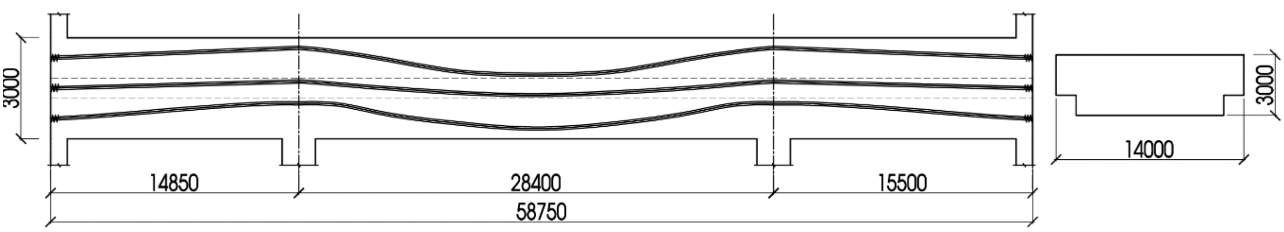

Fig. 4 a) Diagram of post-tension transfer beams; b) Cross section.

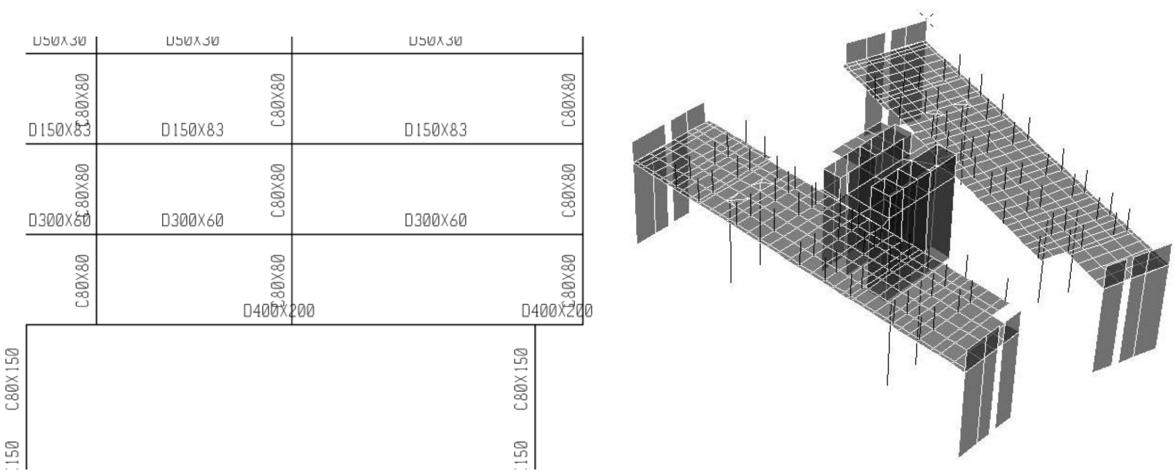

Fig. 5 a) Frame element model; b) Plate element model.

c) Vertical shell model: this model is suitable for transfer beams like deep beams (L/h < 5) or elements on transfer beams with large dimensions (as shear walls). Upper and lower elements are the form of columns or walls lying in the same plane (Fig. 6a).

This type of model can overcome the disadvantages of the two types of models above, it is possible to analyze the biaxial stress state at the connection area between transfer beams and adjacent structures [1].

d) Solid element model: this type is often used when calculating the connection positions between adjacent structures and transfer beams, the upper and lower elements are columns or walls not lying in the same plane (Fig. 6b). The type can analyze the triaxial stress state at the zone between transfer beam and adjacent structure.

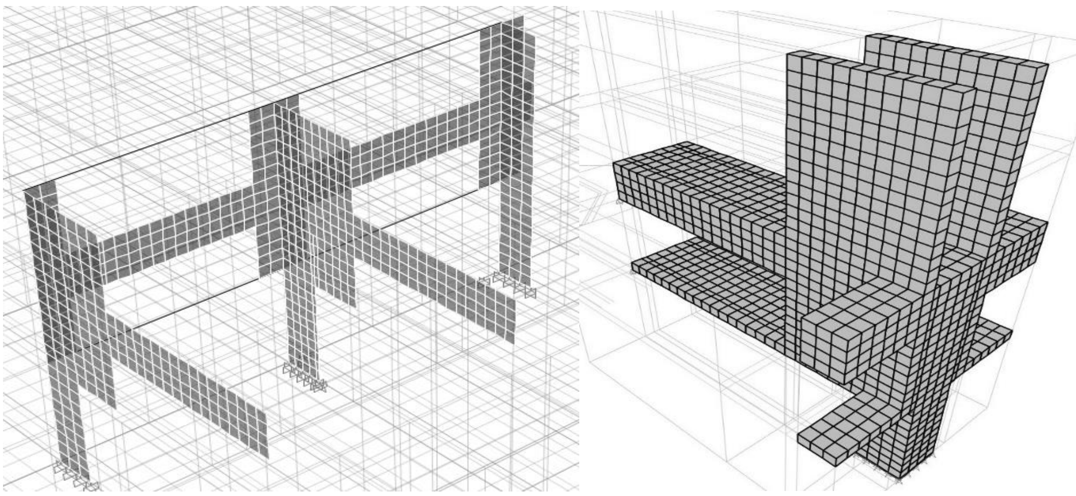

Fig. 6 a) Vertical shell model; b) Solid element model.

In some cases, it may be necessary to combine several models to analysis depending on the complexity of the structure.

2.3 Select the Ductility Class for Building With Transfer Structure in Earthquake Resistant Design

The current standard of earthquake resistant design of Vietnam TCVN 9386: 2012 is derived from the European earthquake standard EC8 [3] classifying the earthquake resistant structure with reinforced concrete into 3 classes of ductility: low ductility class (DCL), medium ductility class (DCM) and high ductility class (DCH). Vietnam is in low usually only requires of DCL or DCM. The design of structures that satisfy the DCM is much more complicated than DCL.

The transfer structure has a much larger size and stiffness than adjacent structures so plastic deformation will not be possible in this type of structure. This argument is also in accordance with the provisions of the standard that the structural system with transfer beams cannot use earthquake resistance with DCM [3]. Thus, to design earthquake resistance for buildings using transfer structures, there are 2 solutions as follows:

- The first method: Selecting the design of earthquake resistant structure system with DCL level. This solution is not recommended in the original EC8 standard, but is allowed in later European standards in countries such as France [5] and the UK [4]. This is the most commonly used way in Vietnam today, although the earthquake load calculated in this way is greater than that in second method.
- The second method: Do not use the transfer structure in the earthquake resistant structure system. The essence of this solution is to

consider the transfer structure as a secondary resistant earthquake structures, not participating in lateral earthquake load and the primary seismic earthquake structure designed with DCM. This approach is fully in accordance with the design standards, but the implementation is quite complicated because it is required to set up a separate earthquake load calculation model different from the calculation model with other load types.

2.4 Structural Analysis According to the Transition Construction Status

In general design principles, structural systems require calculation with construction stages and service stage. However, with normal structures, the construction stages are not usually dangerous to the structure by the service stage, so engineers are often neglected to analyse service stages. With the transfer structure system with large size and weight, the analysis of the structure in the construction stages is quite complicated.

With the transfer structure of the steel material using the factory manufacturing solution and amplification at the construction site, the erection and amplification stages should be carefully calculated because the bearing diagram in construction stages is different with the permanent load-bearing status of the building.

With the transfer structure using pre-stressed reinforced concrete before the design and manufacturing is also quite complicated because of issues related to mass concrete (locate pour-breaks, calculation of pour-breaks, setup of construction methods, maintenance of mass concrete, ...) and post-tension stressing procedure (complete tension before construction of the upper floors or sequential tension during construction).

Following are some analysis of the construction sequence of post-tension concrete transfer beam of Dolphin Plaza project. The overall size of the transfer beam is 56 m long, 3 m high, 14 m wide (Fig. 4), reinforced structure as shown in Fig. 7 [6].

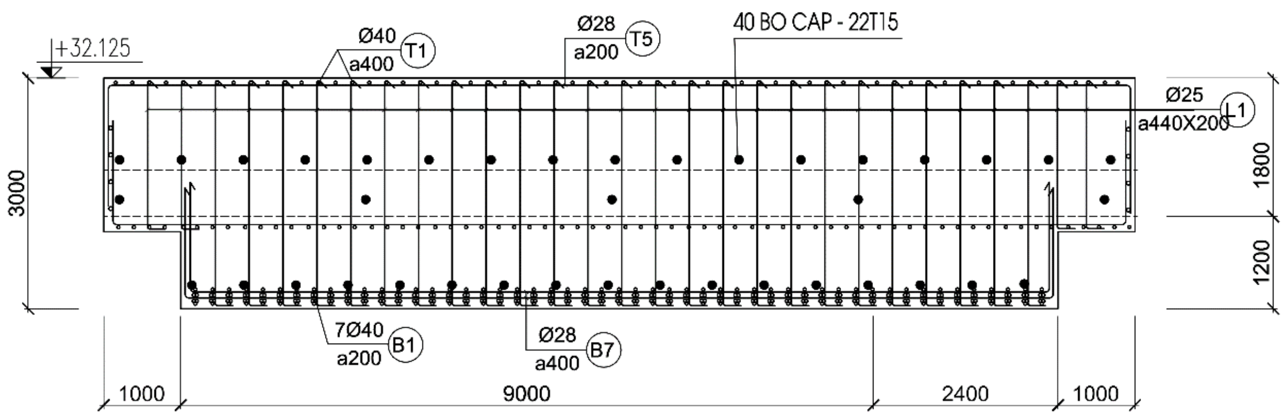

Fig. 7 Structure of reinforced beams.

Basic construction sequence:

- 1st stage: Pour the concrete thickness of 1.2 m, stressing of the lower layer cable when compressive strength of concrete reaches 30 MPa
- 2nd stage: after the concrete layer in 1st stage reaches strength and cable tension, continue pouring concrete 2nd stage with a thickness of 1.8 m, stressing of the upper layer cable when compressive strength of concrete reaches 30 MPa. All upper and middle layer cables are tensioned before the construction of the typical floors.

So why splitting transfer beams into 2 stages of concreting without pouring once with a height of 3 m? The one time pouring concrete method (of 3 m height) with the disadvantage is the expensive scaffolding and formwork system, high-risk construction process, and the maintenance method is also very complicated. The mass concrete volume is too big, very easy to crack due to thermal and shrinkage. Meanwhile, the solution of concreting in 2 phases overcomes the above disadvantages.

In phase 1, the formwork and scaffolding system only needs to be designed to withstand the self weight of the 1.2 m concrete layer (Fig. 8a). In phase 2, the pre-stressed concrete layer of phase 1 is strong enough to support the newly poured 1.8m concrete layer. The technical problem of this solution is to calculate the slip reinforcement link between the two layers of concrete, the reinforced part of this linkage is quite large (Fig. 8b).

Fig. 8 a) Formwork and scaffolding system; b) slip reinforcement.

3. Conclusions

When choosing the solution for the transfer structure, it is necessary to synthesize factors of aesthetics, economy, technology level and construction time. For transfer structures with a span less than 30m, the option of using pre-stressed concrete has an economic advantage.

When analysis of transfer reinforced concrete structure, it is advisable to select and combine calculation models to suit the bearing state of the structure, which can consider the overall and local of the structure.

In most projects that use transfer structures, the selection of DCL for earthquake-resistant structures is an easier way for engineers.

When calculating the transfer structure design, it is necessary to set up detailed construction processes and design calculations for each state in this construction process.

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