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Driving factors and obstacles in adopting structural steel in Hong Kong: Case studies

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Abstract

The construction applications of structural steel mainly include super high-rise buildings and long-span structures. The advantages offered by structural steel to the construction sector and building environment have long been recognised, as evidenced by the increasing market share of structural steelwork in many marketplaces, but not in Hong Kong. The annual import quantity of fabricated steel structures in Hong Kong is 0.2 - 0.3 million tons, which indicates a low demand for structural steelwork in the local construction industry. This study aims to identify the major barriers and potential driving factors to the use of structural steel in Hong Kong. Interviews were conducted with a private developer, three main contractors, and two steel specialist contractors. These industry professionals offered four construction applications that addressed the major problems and driving factors for using steel-framed structures. The four cases included a Chinese opera centre, a swimming pool, a 24-story hotel, and a commercial building. These case studies reveal that steel-framed structures are adopted only for projects that have technical requirements. Otherwise, reinforced concrete structures are used because steel-framed structures are cost-efficient for super high-rise and long-span structures but not for normal types of buildings. The fast construction of structural steelwork can result in an early return on investment, which may outweigh the high construction cost. This advantage will be particularly significant for retail building projects with high land prices in Hong Kong. This study offers strategies for facilitating the fast construction of structural steelwork. If these strategies are implemented to resolve problems, then the application of steel-framed structures to many tall buildings in Hong Kong can be feasible.

Keywords: *Case study; Construction application; Structural steelwork; Composite structure.*

1. Introduction

Steel structural system has been widely used for super high-rise buildings worldwide due to its high strength-to-self-weight ratio and ease of installation; additionally, reinforced concrete offers a broad range of structural systems for tall buildings because heavy concrete structures offer considerable stability against wind loads [1]. With the combination of these two materials, steel-concrete composite structures can provide high tensile strength and compressive strength, which can result in a highly efficient and lightweight structural system.

Buildings constructed with steel-concrete composite structures in Hong Kong are tall or long-spanned. Hong Kong is well known for its skyline with many high-rise buildings. Steel-concrete composite structures are common for high-rise buildings that are higher than 250 m [2]. Large building spans that use steel-concrete composite structures can provide light and aesthetical roof covering, as well as flexible and column-free internal spaces. Steel-concrete composite structures can also offer significant benefits in the design efficiency and construction speed of buildings that have technical requirements on structural steel [3,4].

Time, cost, and resource usage are the key issues that must be considered in selecting a construction method [5]. The lack of experienced engineers, training, and fabrication facilities and the prevalence of reinforced concrete structures are the major factors limiting the application of structural steel in North Cyprus [6]. Wong [3] pointed out that the use of structural steel in Hong Kong remains limited for normal building projects because of the high construction cost. The economic and social characteristics of Hong Kong have markedly changed since this study was published in 2003. Nevertheless, the steel-concrete composite technology has yet to be adapted to normal building projects in Hong Kong, which has become far behind the other developed economies.

The current study aims to identify the key issues hindering the adoption of steel-concrete composite structures in Hong Kong and formulate viable marketing strategies for the active development of steel construction. The remainder of this paper is organised as follows. First, the application of steel-concrete composite structures in Hong Kong is briefly introduced. Second, four cases, including a Chinese opera centre, a swimming pool, a 24-story hotel, and a commercial building, are presented to identify the major driving factors and obstacles for using steel structures. Finally, marketing strategies and opportunities are recommended for the broad use of steel structures.

2. Applications of steel-concrete composite structures in Hong Kong

In Hong Kong, construction materials heavily rely on imports because steel mills and other downstream facilities are lacking. All steel businesses are traders and wholesalers. Other regions, such as Macau, and Singapore, also are placed in a similar situation. The annual import quantity of fabricated steel structures in Hong Kong was around 0.2 - 0.3 million tons (Fig. 1), indicating a sluggish demand for structural steelwork in the past 15 years.

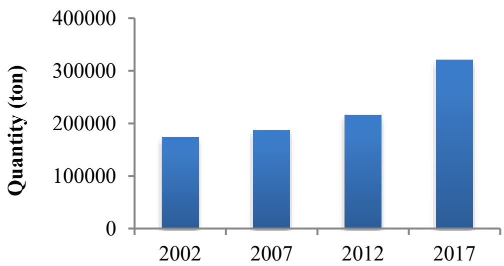

Fig. 1. Imports of steel structures [7-10].

A main contractor reported that only 2% of buildings used steel-framed or composite structures in the Central and Western Districts [11]. Among the 37 tall office buildings completed from 1996 to 2005, only 13.5% of them adopt steel-framed or composite structures [12]. Table 1 provides a list of several iconic buildings that adopt steel-concrete composite structures in Hong Kong in the last two decades. Most of these structures were constructed more than 10 years ago. These projects mainly include office and mix-used buildings. Generally, the height of these tall buildings ranges from 126 m to 469 m, and the total gross floor area (GFA) ranges from 23,500 m^2 to 274,064 m^2. The Hong Kong Convention and Exhibition Centre (HKCEC), the Kennedy Town Swimming Pool, and the Hong Kong Design Institute are large-spanned structures with column-free internal spaces. The total structural steel tonnage of the International Commerce Centre (ICC) is over 27,000 tons [13]. The Hysan Place and the Central Government Complex consumed 9,000 and 5,000 tons of structural steel, respectively. The 62-storey Cheung Kong Centre tower, which is made of concrete core, composite slabs, and composite columns, is an example of a successful steel-concrete composite design [14].

Table 1. Selected steel-concrete composite buildings in Hong Kong.

Year of completion	Name of building	Function	Height (m)	Storey (above ground)	GFA (m^2)
1997	Manulife Plaza (Lee Garden One) Redevelopment	Mix-used	198	50	84,665
1997	HKCEC	Mix-used	n.a.	6	n.a.
1997	Citic Tower	Office	126	33	23,500
1998	IFC Tower 1	Office	210	38	72,880
1998	Sunlight/MLC Tower	Office	147	40	31,981
1999	MLC Millennia Plaza	Office	132	30	n.a.
1999	Cheung Kong Centre	Office	283	63	125,418
2003	IFC Tower 2	Mix-used	388	88	185,805
2004	One Peking	Office	160	30	26,300
2005	AIA Central/AIG Tower	Office	185	35	39,014
2006	Chong Hing Bank Centre	Office	n.a.	26	10,047
2009	Hong Kong Design Institute	Education	n.a.	n.a.	n.a.
2010	ICC	Mix-used	469	108	274,064
2010	The One	Mix-used	143	24	37,455
2011	Central Government Complex	Public	120	27	129,160
2011	Hysan Place	Mix-used	190	36	66,511
2017	Kennedy Town Swimming Pool	Public	n.a.	n.a.	9,100

3. Case studies

To identify the major driving factors and hurdles for using steel-framed structures, interviews were conducted with a private developer, three main contractors, and two steel specialist contractors from March 2016 to July 2017. These industry professionals offered four construction applications, namely, a Chinese opera centre, a swimming pool, a 24-story hotel, and a commercial building. Several of these applications use steel-framed structures but some did not. These case studies can demonstrate the issues underlying the adoption of steel-framed structures.

3.1. Case 1: Xiqu Centre

The Xiqu Centre (Fig. 2) is an art venue specifically built for Xiqu (i.e. Chinese opera) performances. This building also serves as a centre for the production, education, and research of this distinct art form, which helps preserve Cantonese opera and other forms of Chinese traditional art.

Fig. 2. The external façades and internal steel structure of Xiqu Centre.

A steel structure was adopted as the main structural framework for building construction in this project. Interviews were conducted with the client and the main contractor of this project. The interview questions mainly related to (1) the driving factors for using steel structures and (2) the challenges of undertaking structural steelwork and corresponding strategies to overcome these challenges.

The Xiqu Centre was a purpose-built project in which structural steelwork was adopted as the main structure. Time and cost could be saved by using this structural design in this featured project. Given the complex site conditions (e.g., within the Mass Transit Railway (MTR) sensitive area), steelwork was the only option for superstructure due to reduced self-weights.

In view of the surrounding congested traffic and two other concurrently ongoing construction projects nearby, limited site space was a major constraint for the construction of the Xiqu Centre. With close coordination with the client and other parties, the main contractor developed a careful logistic plan for the delivery and off-site storage of steel members.

The main theatre structure comprised long and heavy (2,400 tons) span steel trusses at a high level (50 m). Therefore, an innovative construction method, namely, heavy lifting, was adopted to erect the structural steelworks. The entire heavy lifting sequence was particularly complex. In this regard, the main contractor conducted a detailed risk analysis, trial, actual lifting, and precautionary checking to ensure the efficiency and safety of the heavy lifting works.

To achieve building efficiency, Building Information Modeling (BIM) was completely implemented from the design to the construction phases in this project to assist in the structural design, shop drawing production, and erection of building segments.

The main contractor exerted considerable efforts and resources to train skilled welders who can handle complex and heavy welding joints on M/ML grade plates. The client emphasised that the success of the project was due to the experience and competence of the designers and the contractors, as well as the close collaboration among different stakeholders.

3.2. Case 2: Kennedy Town Swimming Pool Phase II

The Kennedy Town Swimming Pool (Fig. 3) is a relocated public project, which occupies a 0.8 ha site near the Kennedy Town waterfront.

The new complex is a distinct triangular shape structure with a curved roof opening toward the harbour. In addition to an indoor pool (Phase II), it houses a standard outdoor pool and a kiddie pool with a small playground (Phase I). Phase II features a reinforced concrete base and a steel roof. The roof spans a column-free space with transparent ETFE (ethylene tetrafluoroethylene) cushions overhead to admit daylight, offer views, and reduce heat loss and echoes from hard surfaces. Glass window walls are proposed for Phase II to provide cross-ventilation. Zinc cladding is selected for its corrosion resistance to various weather conditions. Moreover, the low sheen and matte finish of zinc can reduce the reflections affecting neighboring residential buildings [15].

Fig. 3. Triangular shape structure of Kennedy Town Swimming Pool Phase II.

Interviews were conducted with the main contractor and the steel specialist contractor of this project. The distinct triangular shape structure of the swimming pool was the key driving factor for using steel structures. This purpose-built project presented several technical and logistic challenges.

The erection of heavy steel members (e.g., the heaviest steel member weighs 21 tons) was challenging in this project. Given a triangular-shaped site and the single material delivery route, limited site space was the major constraint for the erection of structural steelwork. In this regard, a just-in-time steel delivery system was devised to overcome these site constraints. The welding procedures were complicated to connect those heavy steel members. Hence, BIM was used in this project. The 3D figure produced by BIM helped identify the potential clashes at an early stage and resolved problems prior to the actual construction work.

The New Engineering and Construction Contract (NEC3) was also executed in this project. The use of NEC3 could improve the project delivery, develop integration and partnering, and facilitate a fair and appropriate allocation of risks. The main contractor indicated the advantages of NEC3 including (1) the problems and disputes were easily solved, (2) management and decision-making were efficient, and (3) the project completion was advanced by 2 weeks.

3.3. Case 3: Hotel

A private developer initially intended to adopt a steel composite structure for building a new hotel (height, 102 m; GFA, 32,000 m^2; and 24-storey building with approximately 700 rooms). Nonetheless, upon the completion of the feasibility study and cost estimation, the idea was withdrawn, and a traditional RC structure was adopted. Interviews were conducted with the developer and its in-house contractor to explore the reasons underlying their decision to change the structural design.

The interviewees generally compared the differences in cost and programme between a steel-concrete composite design and a RC design, as shown in Table 2. The construction cost of the composite structure was approximately HK$ 200 M higher than that of the RC structure. The project duration for the composite structure was half of a month shorter than that for RC, which contributed none to an early return on investment.

The client pointed out that a high construction cost was the predominant obstacle for using the steel-concrete composite structure in this project. Although the composite structures are highly beneficial for super high-rise buildings in Hong Kong, they may not have been cost-efficient for a 24-storey building. In addition, the prolonged time for structural design, design approval procedure, and material procurement process resulted in insignificant time saving for the composite scheme. Consequently, no financial benefit was attained due to a half-month early completion of the project with composite structures.

Table 2. A comparison of time and cost between composite and reinforced concrete (RC) designs.

	Current RC design	Original composite design
Key features of structure	RC core wall, shear wall	RC core wall, steel composite beam, structural steel frame, steel column and cross bracing shear wall
Duration		
Contract period (months)	34	33
Preparation works (months)		
- BD drawing preparation	1.5	1.5
- BD submission and approval	3	3.5
- Tendering and award of sub-contractor	3.5	3.5
Total (months)	42	41.5
Breakdown of construction cost (HK$)		
- Direct supply material contract only	260 M (19%)	260 M (16)
- Labour (supply & install contract)	820 M (58%)	-
- Supply, fabricate, and install contract for structural steelwork	-	1020 M (64%)
- E&M	320 M (23%)	320 M (20%)
Total	1400 M	1600 M
Cost breakdown of structural steel (HK$)		
- Structural steelwork	-	149 M (74%)
- Rebardek® steel deck		26 M (12%)
- Fire enclosure		20 M (10%)
- Sound insulation		8 M (4%)
Total		203 M

3.4. Case 4: A Commercial Building

An interview survey was conducted with a steel specialist contractor. The contractor proposed a steel-framed scheme to a private developer. Fig. 4 provides the construction cost for a Grade A commercial building with a GFA of 95,000 m^2 under the reinforced concrete and steel-framed schemes. The building cost of the steel-framed scheme was 20% higher than that of the reinforced concrete scheme, and the steel-framed scheme could save 20% and 6% of the foundation and preliminary costs, respectively. Overall, the total construction cost of the steel-framed scheme was HK$ 24.5 M (0.7%) higher than that of the reinforced concrete scheme.

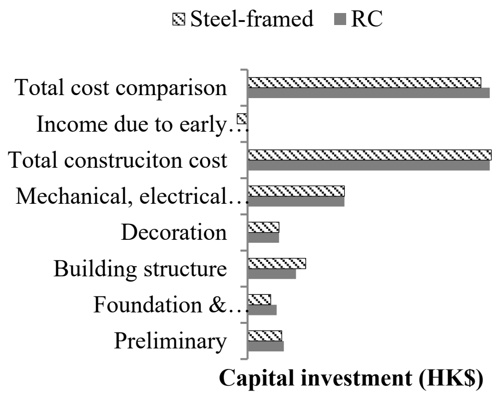

Fig. 4. Cost comparison between reinforced concrete (RC) and steel-framed schemes.

However, the construction speed of the steel-framed scheme can result in five-month earlier completion, thereby resulting in a total income of HK$ 150 M (assuming that the rental income per month is HK$ 30 M). Therefore, the steel-framed scheme can generate a net saving of HK$ 125.5 M. With regard to the total cost comparison, the steel-framed scheme may save 3.6% of the capital investment compared with that of the reinforced concrete scheme. Actually, the average monthly rents of the A grade private offices can be ranged from HK$ 370 per m^2 per month in Kowloon Bay/Kwun Tong districts to HK$ 1100 per m^2 per month in Central. For this case, the monthly rental income could be HK$ 30 M to 100 M. A total of HK$ 150 M to 500 M income can be received due to 5 months early completion of the project. In view of this, the use of steel-framed structures for commercial buildings with high land prices can benefit the client. The cost-benefit analysis by the steel specialist contractor demonstrated that steel-framed structures could reduce the foundation and preliminary costs and achieve early completion, which contribute to an early return on investment. This benefit may outweigh the increased construction cost.

4. Marketing strategies and opportunities

Fast construction is commonly recognised as a remarkable advantage for structural steelwork. First, off-site prefabrication can overlap with the foundation or other works and ultimately reduce the actual on-site time. Second, the construction programme is relatively unaffected with poor weather conditions. Third, the fast speed of erection may contribute to an early project completion, which results in an early occupancy of the property and an early return on investment. The financial benefit of the steel-framed scheme is demonstrated by Case 4 but not by Case 3. The key argument lies in the high construction cost and insignificant time saving by adopting a structural steel design.

Structural steel materials have remained expensive for many years in Hong Kong. To minimise the construction cost of structural steelwork, technical know-how in cost optimisation design should be facilitated. Therefore, education, training, and continuing education on effective design and construction, codified methods and design software, and R&D on steel solutions addressing technical and cost issues should be fundamental aspects of the marketing strategy, so that design and consultation engineers can efficiently design steel structures.

An early completion and occupancy of a project can be achieved by fast-track construction. A collaborative relationship among different stakeholders should be developed to make organisations work smoothly and successfully. For example, the Design-Build delivery system allows fast-track schedules and effective integration of design and construction services, thereby resulting in short total project duration and satisfying the client's needs. The use of the NEC3 can improve project delivery, develop integration and collaborating, and facilitate a fair and appropriate allocation of risks. The early completion of the Kennedy Town Swimming Pool may be a result of such a collaborative contractual arrangement. Furthermore, structural steel experts from regulatory agents should manage the approval procedures to accelerate the approval process and consequently shorten the total project duration.

Early completion can result in an early return on investment of retail buildings in Hong Kong, which is particularly significant for projects with high land prices. The key issue is the facilitation of a fast construction of structural steelwork, which requires a close collaboration among clients, contractors, engineering designers, steel fabricators and suppliers, and regulatory authorities.

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