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Study on Design Method of a Novel Precast Prestressing Composite Frame Based on African Manner

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ABSTRACT

Precast composite structures are new trend in construction technology in China due to their high sustainability and structural performance. As Chinese construction companies enter Africa continuously, the Chinese developed technologies are increasingly applied in Africa. A novel precast prestressing composite structure, developed in China, is believed to have a good prospect in Africa. In this study, a design method of the novel precast structure based on the African design system was developed to promote the application in Africa.

The structural design systems in Africa and China were compared to help designers know the difference between the two design systems and develop a better design method for the new precast prestressed composite frame in Africa. It can be found that the basic theory of the two design systems is similar, but the technical design parameters and equations are different.

The structural design method of the novel precast structure was built with African design system. The basic structural design steps based on the limit state method according to Eurocodes were established, and the seismic design process for the novel precast structure was also developed based on equivalent lateral seismic force method. Some important structural details of the novel frame for earthquakes based on African manner were presented.

The developed detailed design method of the novel structure was applied by designing a four storey novel building structure expected in Huye City at Southern Province of Rwanda. The design results were validated by comparison with results of the novel four storey building structure constructed in Suzhou, China. It is shown that both design systems provide safe design since all the results are within allowable limit, and the Chinese design method is more economical but the African design method is more conservative.

Keywords: Design method; precast composite structure; prestressing; African manner

History
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1. Introduction

Since the African continent has become an urbanization and rising investment destination in the world, Chinese companies have been carrying out construction projects in different African countries in line with sustainable development. Chinese companies integration into African market is growing over years. Since 2005, China won 32% of their total international revenue from African countries [1].

In the construction industry in Africa, it was developed based on China relationship with African Countries, as a result, Chinese companies expanded across Africa in construction industry. Chinese Construction Firms(CCFs) have had a good record in Africa basically due to its advanced technology in construction projects, procurement of materials, financial sources and environmental safety. Recently, China has introduced belt and road initiative program which was intended to integrate Africa into Chinese constructed sustainable infrastructure development. Since 2000 to 2017, China choose belt and road initiative countries such as Djibouti, Ethiopia, Kenya and Tanzania to be given a loan linked to direct resource exploration and infrastructure projects usage. Due to that loan these countries received, some building and transportation projects have been implemented [2] by CCFs. A research showed a high competition where 40% of contracts for buildings and transportation projects in Africa won by CCFs [3].

A case study of Tanzania and Zambia showed a large amount of the incorporation of Chinese companies into construction industry of Africa, on the ground that the indigenous companies have lack of financial and technical capacity in major large scale projects, consequently, Chinese companies based on these countries across Africa have big natural resources and evenly large and stable market [4]. The Zambia's construction industry was developed and is being flourished by Chinese construction companies through bilateral cooperation between China and Zambia [5].

However, the CCFs face the same challenges as other construction companies such as political and economic instability, poor quality of local workforce and construction materials [6]. Especially, they are not confident to use local labor due to communication barrier and lack of technical technologies among African workforce. Not only this challenges, but also include low operation and maintenance skills which require a more conservative design with high safety [7].

On May 2, 2018, construction of the tall building shown in Figure 1 started in Egypt, and the 385 m high Iconic tower has offices, hotels and businesses. The composite tall building structure covers 65,000m^2 with 2 basements and 78 floors above ground level. The Chinese Company called China State Construction Engineering Corporation (CSCEC) is implementing the project. The exchange of ideas between Egyptian and Chinese engineers will improve the modern construction method and better cooperation in infrastructure development design.

Figure 1. Iconic Tower in CBD Egypt (385m high), photo taken June17, 2021 with view of modern buildings.

They exist different types of composite elements including steel-concrete composite, timber-concrete composite, steel-timber composite, and plastic-concrete composite. Steel-concrete composite is the composite element that is most commonly used in construction. Precast composite structure refers to the use of structural steel and precast concrete made together so that the structure behaves as one element. This precast composite structure has the purpose to use the best characteristic strength of both different materials and provide best performance that is more stronger than it had when the individual components been used together without monolithic liaison. The precast composite structure have great importance: shorten the time for construction, good performance and value, energy saving and emission reduction. In addition, the concrete encasement protect the structural steel from corrosion and fire and composite deck provide an integrated services within the channels.

There are numerical investigations on steel-concrete composite structures, the literature review for this study will focus on composite structural members such as concrete filled steel tube columns, precast hybrid steel–concrete beams and the steel-concrete composite connecting joints[8].

Concrete is a material that is strong in compression, but weak in tension. On the other hand, structural steel is very strong in tension, even when it is used in relatively small quantity. Steel-concrete composite uses compressive strength of concrete alongside structural steel's resistance to tension forces, and when they are bound together results in forming a very high stiff material unit. Due to the advantages such as fire resistance, combining high strength, long life capability and lightness of steel with stiffness, good ductility and damping, good energy dissipation capacities and economy of concrete, Steel-concrete composite construction has been increasingly used over decades in building industry, bridges, high rise building construction and car park[8,9].

Referring to the Figure 2, some typical examples of composite subassembly are presented such as composite beam, composite slab and composite columns.

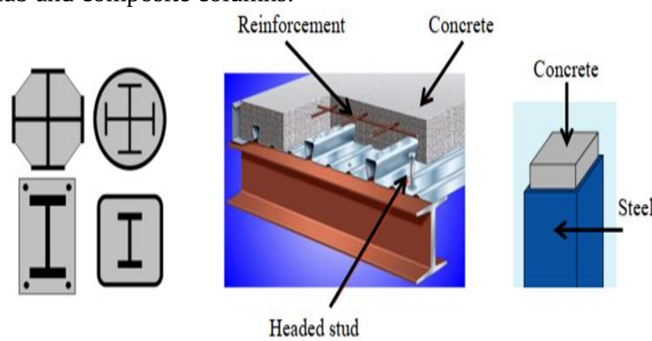


Figure 2. Details of a composite beam, slab and columns [9].

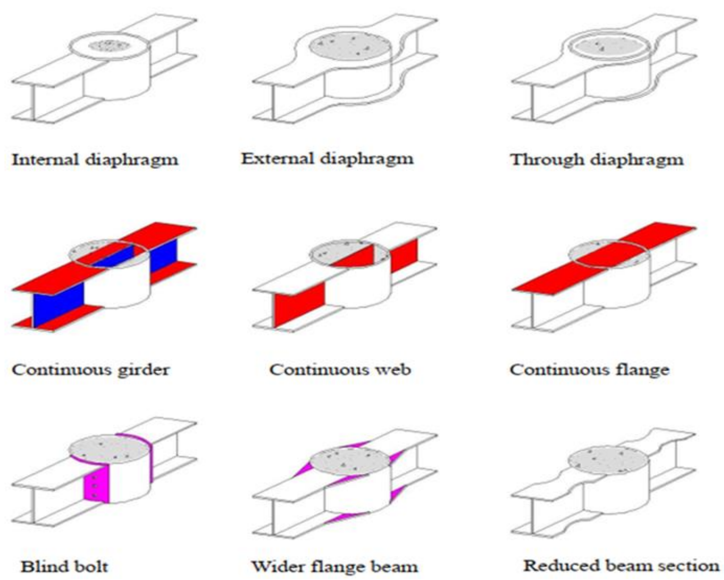


Figure 3. common CFST joint configurations [9].

Steel–concrete composite joints are accumulation of parts that transfer forces from one member to others, the forces and moments of the members must be resisted at the point of joint. Eurocode4(EN1994-1-1.5.2.8)[10] provided definition of composite joint: a joint between a composite member and another composite, steel or reinforced concrete member, in which reinforcement is considered in design for the resistance and stiffness of the joint. For the joints to respond effectively in moment resisting frames, they have to satisfy the following criteria:

1.The applied design moment should be always less than the moment capacity of the joint.

2. The joint must have sufficient rotational stiffness.

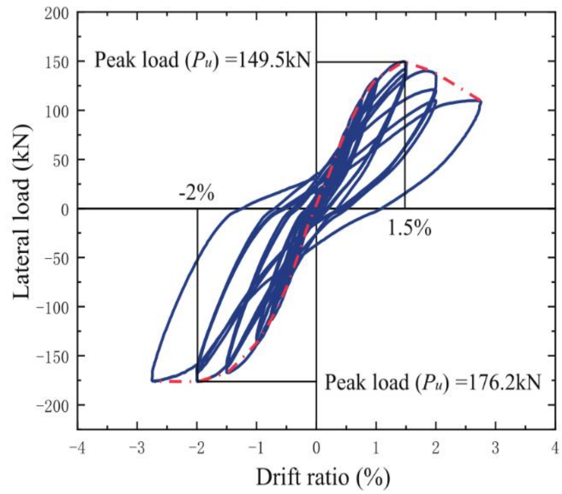
3. The joint should have adequate rotational capacity (subsequently referred to as ductility) to allow the connection to work as plastic hinge.

4. The applied shear resistance must be less than the shear resistance of the joint. Refer to the Figure 3.

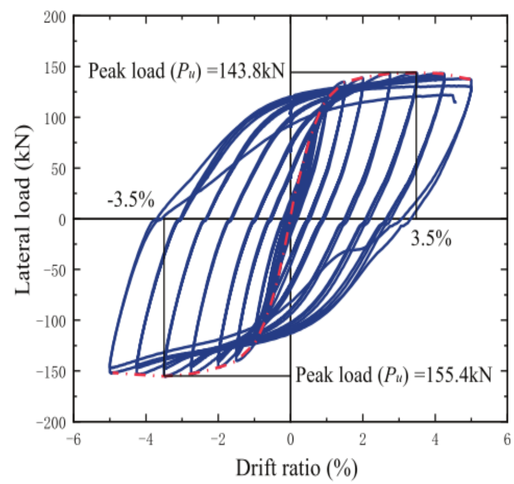
S. Feng, D. Guan, Z.Guo et al [11] developed the assembly of the joint between a new hybrid H-steel precast concrete (HSPC) beam and concrete-encased filled steel tubular (CFST) column as shown in Figure 5 and 6. It was developed through laboratory experimental set up in order to assess the seismic performance based on ductility, energy dissipation capacity, failure pattern, stiffness degradation and hysteresis curve of the joint. The HSPC was connected to CFST via cantilever H-steel section [12, 13-14].

To assess the suitability of the joint, the cyclic load reversed test was conducted under use of three types of cantilever H-steel beam: untreated beam section (EJ-1), reduced beam section (RBS) (EJ-2) and open web beam (OWB) (EJ-3). The results indicated that the hysteretic bahaviour stability of the joint with reduced beam section occurred at a drift ratio of up to 4.75% (refer to Figure 4) and a significant ductility and the cumulative energy dissipation capacity was 8.8 times that of original specimen. Conversely, the enhancement in the steel section with OWB in subassembly was poor compared to the original specimen. Therefore, the subassembly with reduced beam section(RBS) was considered to resist in seismic region. Refer to the Figure 4 below [15, 16].

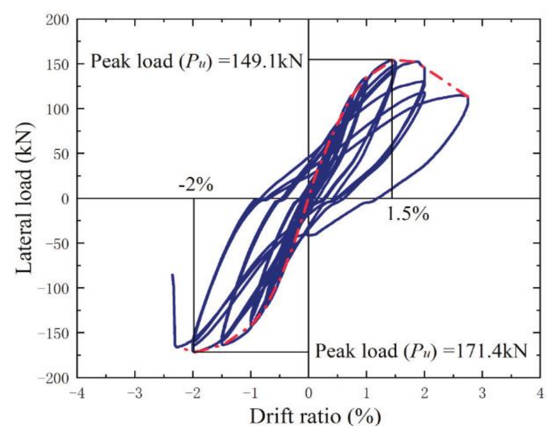
Design methods of the steel-concrete composite design is a crucial step in steel-composite building construction. The steel-concrete composite design is done to make safer the building structure. The major structural composite members in steel-concrete composite structures are reinforced against bending and vertical shear forces. The shear connector are designed and incorporated between the surface of steel and concrete for composite beam and slab [17,18].



(a) Specimen EJ-1

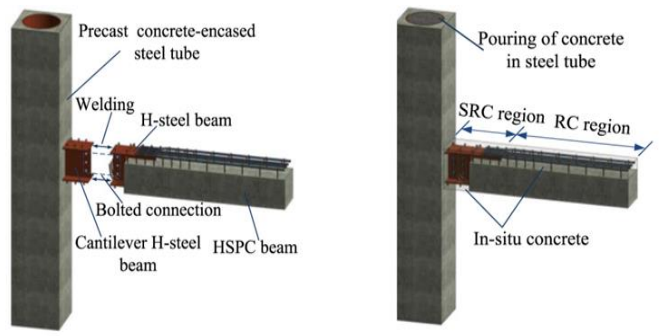


(b) Specimen EJ-2



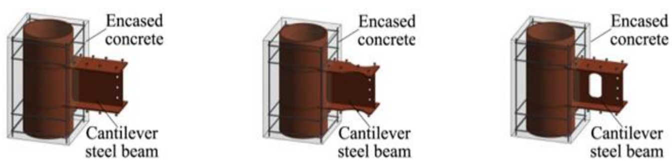
(c) Specimen EJ-3

Figure 4. Hysteresis curves of specimens under cyclic loading [11].



(a) Precast joint in assembly (b) Precast joint after assembly

Figure5. Construction processes of the developed precast joint CFST column and HSPC beam [11].



(a) untreated beam (b) RBS steel beam (c) OBW steel beam

Figure 6. Concrete encased-CFST columns with cantilever H-steel beams [11].

In the common analysis of composite sections, the following conditions are assumed :(EN1994-1-1), as follows:

1.Concerete is assumed to carry zero tensile stresses in both elastic theory and plastic theory.

2. In elastic theory, concrete in compression is transformed into an equivalent area of steel by dividing its breadth by the modular ratio E_a/E_c.

3. Plane sections of the structural steel and reinforced concrete parts of a composite section each before bending remain plane after bending [19,20-22].

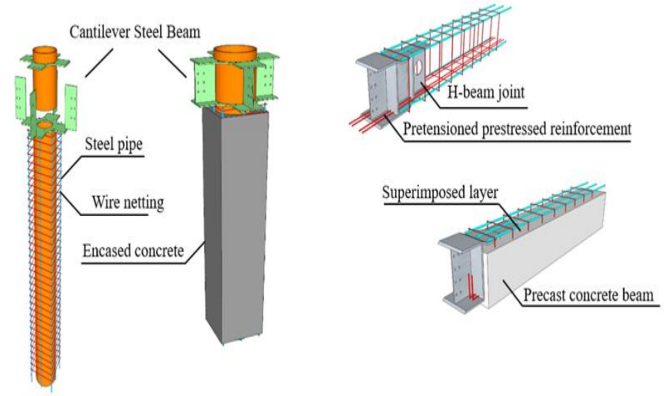
4. in plastic theory only,

a) Concrete in compression resist a stress of $0.85f_{cd}$ where $f_{cd}=f_{ck}/\gamma_C$, which does not change over the whole depth between the plastic neutral axis and the most compressed fibre of the concrete.

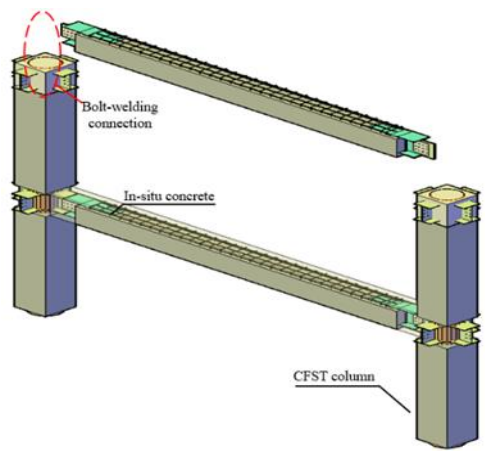
b) The structural steel member is stressed to its design yield strength $f_{yd=}f_y/\gamma_A$. Transformed sections are not used.

2. The novel precast prestressing composite frame

As the development of the architectural industrialization career in China, tremendous precast structures are designed and constructed across different areas of China, including precast concrete structures, precast steel structures and precast timber structures. However, the widely-applied precast concrete structures are emulative system, of which the construction efficiency is relatively low relying on a large amount of labors. Precast steel structures require coatings and other protective measures for fires and corrosions, making the construction cost relatively high. Therefore, many investigators and engineers are developing and seeking a satisfactory precast structure.



(a) Details of the components



(b) Connection details of the columns and beams

(c) The constructing stage of the structure

Figure 7. The novel precast prestressing composite frame in Suzhou, China

A novel precast prestressing composite structure, which was believed to have a good prospect of application, was developed by the research group that the author belonged to in School of Civil Engineering at Southeast University, China. The columns are made of concrete filled steel tube (CFST) surrounded by reinforced concrete wall for fire proofing. The beams are precast prestressed beams in the middle span and the ends are made with H-steel beam connection embedded into precast beam in the joints. A through diaphragm was used to connect either circular or rectangular steel tube column with H-steel cantilever beam embedded in precast prestressed beam as shown in the Figure7. At construction sites, the precast prestressed composite beams are connected to the precast composite columns through bolts for the webs and weldings for the flanges.The columns are connected with each other by steel plates welded at columns end sides and with bolts to connect steel plates at both columns ends connection. After the installation of slabs, concrete is poured for the monolithic layers. This novel structure has been constructed as an office building by ZYF Company in Suzhou, China, proving the high efficient construction and satisfactory load-bearing capacity of static loadings.

The use of precast prestressing steel-concrete composite units is essential in promoting the sustainability and resilience of infrastructure in Africa and around the world in general. In addition, precast units are environmental friendly and reusable. Prestressing units will allow load balance to be placed in the structure to anticipate service loads. This will bring many benefits to the building frame such as:

1. Span can be increased without increasing structural depth

The load balance reduces the service deflection, which causes the span length to increase without the need for structural depth increase, and the number of supports is reduced.

2. Reduction of structural thickness dimensions

The lower service deflection allows the use of thin structural sections in the building that lead to more service areas.

3. Construction time is reduced;

The precast beam can be installed and connected to the precast column in the similar way with the quick construction of steel structures. The precast units are fully stretched and braced within five days, after which a few formworks are removed and can be quickly used for the next phase of building construction. Alternatively, when the precast unit is manufactured at the factory, it must be installed in a very short time with minimal labor cost.

4. Cost savings for fire-proof materials;

For the steel components in this structure, the concrete is poured to encase them in a manufacturing factory as fire-proof materials, which is cheap and easy to be prefabricated. The layers of the fire-proof concrete outside the steel elements commonly remain approximately 50 mm. Therefore, the steel components are protected well with relatively low costs.

For this novel precast prestressing composite frame structure, as the advantage of the force combination; the encased steel is more protected against corrosion and fire, and no maintenance is required. The concrete inside rectangular steel tube column is well confined and no need of additional rebar in concrete because the column bearing capacity is adequate. The H-steel beam section in the ends of beam in the connection between beam and column is more strong compared to other connection in precast structures. The connection of column with each other is more strong compared to other connection in precast structures. It consists of steel plate welded on column sides at end of each column and the connection is made of other steel plate fixed at end of each side of columns with the help of bolts.

3. Materials and Method

3.1. Materials

The novel precast prestressed composite frame was developed and applied in China. A comparison was made between the structural design system in Africa and China to know the difference, which can help develop a better design method for the new precast prestressed composite frame in Africa. In general, the structural design system in Africa is based on Eurocode0 for the basis of structural design, Eurocode1 for the loads on structures, Eurocode2 for the design of reinforced concrete structures, Eurocode3 for the design of structural steel structures, and Eurocode4 for the design of steel-concrete composite structures, and Eurocode8 for the design of earthquake resistant structures in most of the African countries.

There are many design codes for structures in China. In this paper, the general structural design system in China is thought to be based on the several basic design codes, i.e., GB50010 Code for the design of reinforced concrete structures, GB50009 Load code for design of the building structures, GB50017 Code for design of steel structures, JGJ138 Code for design of composite steel structures and GB50011 Code for seismic design of buildings. Therefore, the comparison of both Eurocodes and Chinese codes was employed to help Chinese and African designers to know the two structural design systems well and the difference between them, and the developed design method according to African manner was based on limit state method and design steps were proposed.

3.2. Method

The possible design method based on African manner is the limit state method according to Eurocode0, Eurocode1, Eurocode2, Eurocode3, Eurocode4 and Eurocode8. A three-D model was transformed into a two-Dimensional plane frame. Computer program (ETABS software) can be used to assist in analysis and design of the frame members based on stiffness method in Rwanda, Africa. The frame member sizes are selected, loads of the frame are estimated, bending moment, axial and shear forces are computed, and prestress is applied. Then the planned structure is checked for both ultimate limit state and serviceability limit state. The analysis and design is done based on the assumption that the materials behaviour are linear and elastic [23]. The design method of critical elements such as composite beam, columns, and connections are discussed in design steps below.

3.2.1. Basic design steps of the novel structure based on African manner

At the initial stage, the structural modelling of the proposed precast prestressing composite frame was developed. The simplified structural analytical model was developed based on load distribution, geometry of the structure, its supports and the estimated deformation of the structure [23]. Then, the critical elements can be designed following the design steps and design formulas which are expressed below.

Step1.Establishment of the structural layout plan

Step2.Identification of the Elements of the frame and materials properties

Step 3.Determination of the characteristic values of loads

Step 4. Preliminary design of member sizes of a structure.

1. Preliminary design of beams

The basic parameter of the beam can be obtained using the following expression first:

$$Z_{btm} \geq \frac{M_T - 0.85M_0}{f_{ct,t} - 0.85f_{cc,0}} \tag{1}$$

where Z_{btm} is the section modulus at the bottom fiber of the beam; M_T is the moment due to total service load; M_0 is the moment due to selfweight; $f_{ct,t}$ is the tensile stress limit of concrete at bottom fibre after prestress forces finish transfering; $f_{cc,0}$ is the compressive stress limit of concrete at bottom at prestress forces finish transferring. According to Code EC2, the values of $f_{ct,t}$, $f_{ct,0}$, $f_{cc,t}$ and $f_{cc,0}$ are concrete stress limit which are selected for design.

Then the trial depth of beam section is given by the following expression:

$$h \geq \sqrt{Z_{btm} \times 6/b_w} \tag{2}$$

where b_w is the width of beam section which is assumed according ordinary details of beams[23].

Check that the deflection of the initially-determined beam according to the requirement, i.e., the trial section should satisfy the following expression:

$$I \geq \beta \frac{W_{tot \times} l^4}{E_{cm} V_{max}} \tag{3}$$

where W_{tot} is the total unbalance load; L is the span of the beam; E_{cm} is the elastic modulus of concrete; V_{max} is the limiting maximum deflection, $l/500$; and β is deflection coefficient equal to 5/384.

Determine prestressing force and eccentricity required at midspan of the beam. The section properties α_{top} and α_{btm} are obtained by the expressions, i.e., $\alpha_{top} = A/Z_{top}$ and $\alpha_{btm} = A/Z_{btm}$, where A: Cross section area, α_{top}: the ratio of area to section modulus at top fiber of beam and α_{btm}: the ratio of area to section modulus at bottom fiber of beam, and Z_{top}: section modulus at top fiber of beam [23].

The following expression provides the upper and lower limits of prestress at transfer and after transfer, respectively: at transfer

$$P_{mo} \leq \frac{Af_{ct,0} + \alpha_{top} M_0}{\alpha_{top} e - 1} \tag{4}$$

$$P_{mo} \leq \frac{-Af_{cc,0} + \alpha_{btm} M_0}{\alpha_{btm} e + 1} \tag{5}$$

after transfer

$$P_{mo} \geq \frac{-Af_{ct,t} + \alpha_{btm} M_T}{\Omega(\alpha_{btm} e + 1)} \tag{6}$$

$$P_{mo} \geq \frac{Af_{cc,t} + \alpha_{top} M_T}{\Omega(\alpha_{top} e - 1)} \tag{7}$$

where Ω is time-dependent loss of prestress and e is excentricity to resultant prestressing force; P_{mo} is prestress force applied $f_{ct,t}$: the tensile strength of concrete after transfer, $f_{ct,0}$:the tensile strength of concrete at transfer , $f_{cc,t}$:compressive strength of concrete after transfer and $f_{cc,0}$:compressive strength of concrete at transfer[23,24-26]

The two ends of beam are made of short H-steel beam embedded into concrete precast prestressed beam. The top and bottom steel reinforcement are welded on top and bottom of H-steel beam flange with the help of stud connectors. According to expermiment done [27]. The connection between steel reinforced concrete (SRC) region and reinforced concrete (RC) region is designed following the model of the experiment done. Refer to Figure 8, below [28, 29-30].

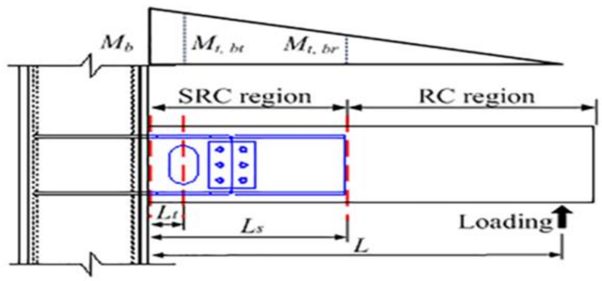


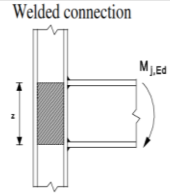
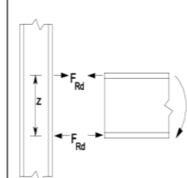
Figure8. Calculation sketch of hybride steel precast concrete (HSPC) beam [11].

The distance L_t, L_s, L is taken similar to that one in experiment. However, the dimensions of H-steel beam section and concerete filled rectangular steel tube section can be different according to the loading of the structure being designed. In Figure 8, M_b is the ultimate flexural capacity at the interface between beam and column, and can be calculated using EN1994-1-1, as follows:

$$M_b = F_{Rd} \times z \tag{8}$$

Where F_{Rd} is the axial force resistance, and z: lever arm. Details can be seen in Table 1 below.

Table 1.welded connection at the interface between beam and column (EN1993-1-8, 6.2.7)

Type of connection	Centre of compression	Lever arm	Force distributions
a) Welded connection 	In line with the mid thickness of the compression flange	$z = h - t_{fb}$ h is the depth of the connected beam t_{fb} is the thickness of the beam flange	

In Figure 8, above, $M_{t,bt}$: is theoretical flexural resistance in the central section of H-steel region; $M_{t,br}$: is the theoretical flexural resistance of the end section at RC region; M_{bt}: is the ultimate flexural capacity of the central section of H-steel beam; M_{br} is the ultimate flexural capacity of the end section at RC region.

For the plastic hinges to be formed within SRC region, the following equations must be followed:

$$M_{bt} / M_{t,bt} \leq 1 \tag{9}$$

$$M_{br} / M_{t,br} \geq 1 \tag{10}$$

2. Preliminary design of column

The size of the column is derivered from plastic resistance to compression $N_{pl,Rd}$ of a composite cross-section which is expressed by the following equation:

$$N_{pl,Rd} = \eta_a A_a f_{yd} + A_c f_{cd}\left(1+\eta_c \frac{t}{d}\frac{f_y}{f_{ck}}\right) \quad (11)$$

Where $N_{pl,Rd}$: plastic resistance to compression,t: thickness of steel tube ,d:diameter of steel tube , A_a: cross section area of steel f_{yd}:design tensile strength of steel, A_c:cross section area of concrete, f_{cd}:design compression strength of concrete,f_y:yield tensile strength of steel,f_{ck}:characteristic tensile strength of steel, η_a and η_c are reduction coefficients of steel and concrete respectively.

In Eq.(11), no longitudinal steel reinforcement is considered according to the novel precast composite structure.

The increase in strength of concrete due to confinement in concrete filled circular tube may be taken into account if the relative slenderness λ defined in EN1994-1,Clause 6.7.3.3(2) does not exceed 0.5 and e/d <0.1, where e is the eccentricity of loading given by M_{Ed} /N_{Ed} and d is the external diameter of the column. Otherwise stated, for e/d > 0.1, the values of η_a = 1.0 and η_c = 0, then $N_{pl,Rd}$ should be calculated by the following equation:

$$N_{pl,Rd} = A_a f_{yd} + A_c f_{cd} \quad (12)$$

Step 5. Load estimation

Step 6. Estimation of load combination for ultimate limit state design

The following equations can be used to determine the design ultimate load (W_{Ed}):

$$W_{Ed}=1.35\times Deadload+1.5\times Liveload \quad (13)$$

$$W_{Ed} = 1.35 \times Dead\ \ load + \psi_0, L \times Live\ \ Load \quad (14)$$

where ψ_0 is the factor for buildings according to EC0 (1990:2001,Table A1.1).

Step 7. Design of beams

1. Design of precast prestressing reinforcement

Using the above Equations 4 through 7, the minimum required prestressing force at mid-span that satisfies all four equations can be obtained with the eccentricity to the resulting prestressing force at middle span of beam.

The immediate losses at mid-span is assumed and the jacking force is determined as following :

$$P_j = \frac{P_{mo}}{\Omega} \quad (15)$$

where P_j: is the jacking force, P_{mo}:applied prestress.

Assuming a seven-wires strand of 12.7mm diameter, the maximum stress in the tendon at jacking is the smaller value of $0.8\ f_{pk}$ or $0.9\ f_{p0.1k}$, where f_{pk} is the characteristic strength of strand, and $f_{p0.1k}$ is 0.1% proof characteristic strength of strand, hence the jacking force per strand, $P_{jstrand}$ can be $0.9\ f_{p0.1k}$ *$Area\ of\ strand$, and then the minimum number of seven wire strands can be found by jacking force over jacking force per strand.

2. Design of non prestressing reinforcement

a) Design of non prestressing steel rebars in tension

Considering a section of beam, effective prestress, $P_{m,t}$, and the area of prestressing steel, A_p, the cross section have been designed to satisfy the serviceability of the reqirements of the member. With the stress-srain relationship according to EN1992-1-1, and the design moment resistance of the section is calculated as the following equation:

$$M_{Rd1}=\sigma_{pud1}A_p\left(d_p-\frac{\lambda x_1}{2}\right) \quad (16)$$

where σ_{pud1}:stress in strand,A_p:area of strand,d_p:effective depth to strand,x_1:depth to neutral axis, λ:reduction coefficient.If the design resistance(M_{Rd1}) is greater or equal to the design ultimate moment(M_{Ed}), no additional non-prestressing reinforcement is needed, but if M_{Rd1} is less than M_{Ed}, additional non-presstresing reinforcement is required. Hence,

$$A_s \geq \frac{M_{Ed}-M_{Rd1}}{f_{yd}\times z_2} \quad (17)$$

where M_{Ed} is the design ultimate moment; f_{yd} is the yield strength of reinforcement; Z is the lever arm between the design tension force in the additional steel; F_{sd} and the equal and opposite compression force F_{cd2} which results in the increase in the depth of compressive stress block (refer to Figure 9 below) and A_s is the area of reinforcement.

The lever arm between the design tension force in the additional steel can be obtained refering to Figure 9 below as:

$$Z_2=0.9(d_s-\lambda_{x1}) \quad (18)$$

where d_s: effective depth to reinforcement. Non- prestrssing reinforcements are provided in the tensile zone of the section of a beam to provide additional flexural strength when the strength provided by the prestressing steel is not enough. It improves also crack control when cracking is anticipated at service loads.

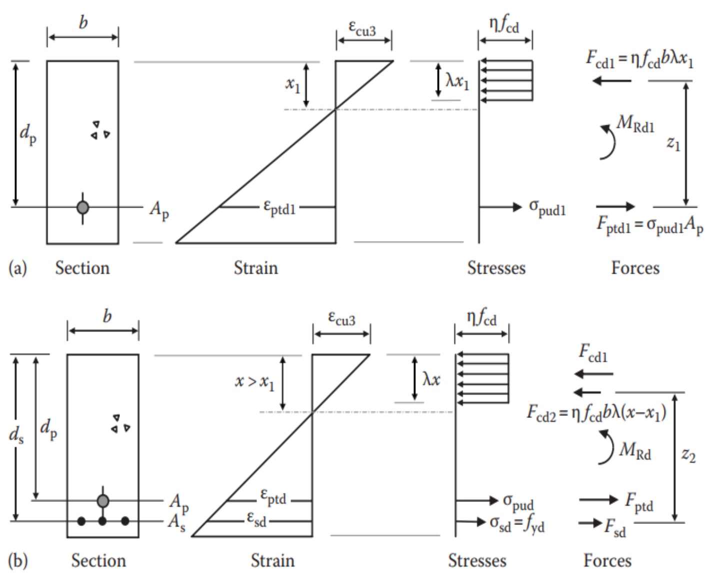


Figure 9.Cross section containing tensile reinforcement [23].

b) Design of non-prestressing steel rebars in compression

Considering the rectangular section of a beam below, the minimum area of additional tensile reinforcement is given by the following expression:

$$A_{s(2)} = \frac{M_{Ed} - M_{Rd1}}{\sigma_{sd(2)}(d_{s(2)} - d_{s(1)})} \tag{19}$$

Where $\sigma_{sd(2)}$:design stress in tension rebar(refer to Figure 10).The minimum area of additional compression reinforcement is given by the following expression:

$$A_{s(1)} = \frac{A_{S(2)}\sigma_{sd(2)}}{\sigma_{sd(1)}} \tag{20}$$

and the strain in both compression and tension reinforcement can be greater than the strain in steel, hence the steel have yielded.

$$\mathcal{E}_{sd(1)} = \frac{\mathcal{E}_{cu3}\ (x - d_{s(1)}}{x} \tag{21}$$

$$\mathcal{E}_{sd(2)} = \frac{\mathcal{E}_{cu3}\ (d_{s(2)} - x)}{x} \tag{22}$$

where $d_{s(1)}$:effective depth to compression rebar, $d_{s(2)}$:effective depth to tension rebar,$\mathcal{E}_{cu3}$:strain of concrete $\mathcal{E}_{sd(1)}$:strain of compression rebar, and $\mathcal{E}_{sd(2)}$:strain of tension rebar. Non- prestressing reinforcement are provided in top of the section to not only improve the strength in compression zone, but also increase the curvature at failure and improve ductility. It reduces long-term deflection due to creep and shrinkage, hence, improving serviceability. Compression reinforcements are also provided to enhance anchorage and bearing for the transverse reinforcement in beams. Closely stirrups are used to laterally brace the highly stressed bars in compression and prevent them from buckling outward [31].

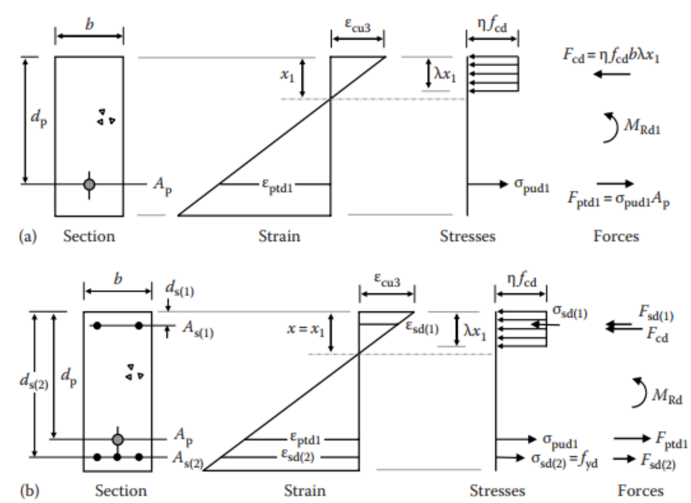


Figure 10, doubly reinforced section [23]

3. Check of the resistance to bending at mid-span

The design load W_{Ed} is found by using Equation 13 or 14 in Step 6 and the design moment (M_{Ed}) at mid span is found by using this expression:

$$M_{Ed} = \frac{W_{Ed}L^2}{8} \tag{23}$$

The ultimate resistance moment of a rectangular section containing both prestressing steel and non prestressing steel is found by this expression:

$$M_{Rd} = \sigma_{upd}A_p\ (d_p - \frac{\lambda x}{2}\ ) + f_{yd}A_s\ (d_s - \frac{\lambda x}{2}) \tag{24}$$

where $x = \frac{f_{pd}\ A_p}{\eta f_{cd} b \lambda}$ is the depth to the neutral axis of the section, $f_{pd} = 0.9 f_{pk}/\gamma_s$ is the design strength of prestressing steel, A_p is area of prestressing steel, f_{cd} is the design compressive strength of concrete and b is the width of beam section, d_p and d_s are effective depth to prestressing steel and non prestressing steel, respectively.

For a section with non prestressing steel, M_{Rd} should be greater than M_{Ed}, which can be computered as follows:

$$M_{Rd} = \sigma_{upd}A_p\ (d_p - \frac{\lambda x}{2}\ ) \tag{25}$$

No non-prestressing steel is required for the section, the section has adequate flexural strength with ductility. Otherwise, the section will require non prestressing steel reinforcement.

4. Check of shear resistance

The shear is checked at 1 m and 2 m from the face of the column support , and whether the shear resistance of the beam is greater than the design shear ,$V_{Rd,c} > V_{Ed}$, should be checked. Shear resistance should be:

$$V_{Rd,c} = \frac{Ib_w}{S}\sqrt{(f_{Ctd})^2 + \alpha_1 \sigma_{Cp}\ f_{Ctd}} \tag{26}$$

where S:is the first moment area of the section, I is the second moment area of the section, $\sigma_{Cp:}$ is concrete compressive stress due to axial load and prestressing, f_{Ctd} is design concrete tensile strength ,b_w:width of beam and $\alpha_1 = l_x/l_{pt2} \leq 1.0$ a reduction coefficient.

5. Minimum clear spacing between pretensioned tendons

Horizontal clear spacing of between pretensioned tendon should be greater than the maximum of $d_g+5,\ 2\Phi$ and 20mm, and vertical clear spacing be greater than the maximum of d_g and 2Φ, where Φ is diameter of pretensioned tendon and d_g is maximum size of aggreagates[31].

6. Design of ends connections of beam

According to Figure 8, the value of M_{bt} and M_{br} can be calculated assuming the rectangular stress block for composite beam in EN1994-1-1 in similar way as the experiment done(Feng et al., 2021). M_{bt} can be obtained based on that the neutral axis is within the web of the H-steel beam and that the sectional area of the top steel flange is equal to that of bottom steel flange. Considering force equilibrium, the equation for reduced H-steel beam section(RBS) as per previous experiment can be obtained as follow:

$$f_{cc}\,bc + f_{aw}A_{w,co} = f_{aw}\,A_{w,t} \tag{27}$$

The equation for RBS region is obtained considering the moment equilibrium:

$$M_{bt} = f_{af}A_{bf}(h\text{-}c\text{-}a_{s,t}) + 0.5f_{aw}A_{w,t}(h\text{-}c\text{-}a_{s,t}) + f_{af}A_{bf}(c\text{-}a_{s,co}) + 0.5f_{aw}A_{w,co}(c\text{-}a_{s,co}) + 0.5f_{cc}\,bc^2 \quad (28)$$

where f_{cc} is the axial compressive strength of concrete that is determined as $0.85f_{cd}$, f_{af} and f_{aw} are the yield strengths of the flange and the web in H-steel, respectively; $a_{s,t}$ is the distance between the flange of H-steel in the tension zone and the tensile edge of the cross section; $a_{s,co}$ is the distance between the flange of H-steel in the compression zone and the compressed edge of the cross section; c represent the depth of the neutral axis. Moreover, A_{uf} and A_{bf} are the sectional areas of the upper and bottom flanges, respectively, in H-steel. $A_{w,co}$ and $A_{w,t}$ denote the sectional areas of the beam web in the compression and tension zones, respectively (refer to Figure 11).

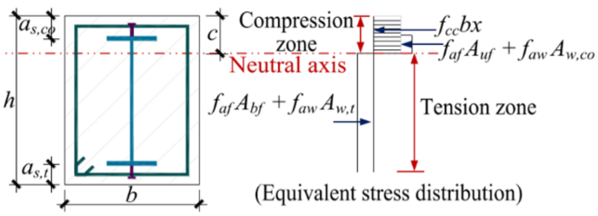


Figure 11. Center cross-section of the reduced beam section (RBS) [11].

The Figure 11 can be used to calculate the flexural resistance under sagging moment

To ensure good strength of the connection between the H-steel beam and RC beam, it must satisfy:

$$A_s \geq \frac{f_{af}\ A_f\ (L-L_s)}{f_s\ (L-L_t)} \quad (29)$$

where A_s is the area of steel reinforcement, f_{af} is the yield strength of steel and ,A_f is the sectional area of the steel flange, L is the distance from the face of column to the point of loading, L_s is the distance from face of column to the end of RC region, and L_t is the distance from face of column to center of H-steel section beam on Figure 8, above.

The required area of the H-steel A_a is determined by

$$A_a f_{yd}\,(h_a+h_t\text{-}h_c/2) \geq M_{Ed} \quad (30)$$

Where A_a: cross section area of steel, f_{yd}: design tensile strength of steel, h_a : depth of steel section h_t:thickness of slab, h_c:thickness of overtoping slab, and M_{Ed}:design moment.

Step 8. Design of composite column

The ultimate moment of resistance (M_u) can be calculated based on stress block diagram for concrete filled rectangular steel tube columns according to BS5400: Part5,C.4.2.5[32] as follows

$$M_u = 0.91f_y\left[A_S\frac{(h-d_c)}{2} + b_t t_f\ \ (t_f + d_c\ \ )\right] \quad (31)$$

$$d_c = \frac{A_s - 2b_f\ t_f}{(b\rho + 4t_f\ )} \quad (32)$$

$$\rho = \frac{0.4f_{cu}}{0.91f_y} \quad (33)$$

where A_s is area of rolled steel section; h is depth of concrete in filled rectangular hollow section, d_c is depth to the neutral axis from most compressed face of concrete; t_f is the average thickness of the flange of steel section; b_f is the external dimension of width of rectangular hollow section; ρ is the ratio of the average compressive stress in the concrete at failure to the design yield strength of the steel.

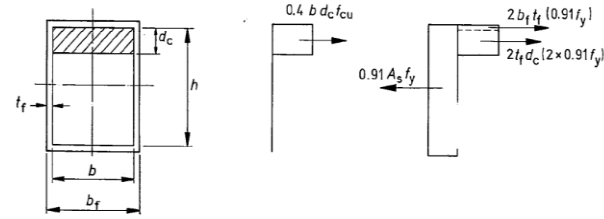


Figure 12. Force diagram for calculating M_u [32].

Step 9. Design of beam to column connections

1. Connections between concrete filled steel tube columns and H steel beams

According to the provision given in EN1993-1-8, steel joint design method can also apply to steel-conrete composite joint design in EN1994-1-1. In the beam-column connection, an H-steel beam is welded onto column by inner diaphragms. The H-steel beam is connected to precast prestressing beam by means of welding H-steel flange with both top and bottom steel reinforcement in precast prestressing beam. At the top of H-steel beam, there is shear studs to assist in preventing horizontal slide between beam and top slab. The H-steel beam embedded on the column and the one embedded in beam are connected by means of welds at top flanges and web plate with bolts at both web sides. The dimension of H-Steel beam are obtained from steel profile data base (Europian beam). To ensure enough strength of connection between the H-steel beam and RC beam , the total area of reinforcement that transmit normal stress to the top and bottom of the beam should be greater or equal to sectional area of the H-steel flange.The design resistance of bolts are given in Table 3.4 of EN1993-1-8:2003[33].

Headed stud connectors are provided and can have the following dimensions: $h>3d$, $d_h>1.5d$ and $h_d>0.4d$, where h is overall height of stud, d_h is diameter of head of stud, d is diameter of shank of stud, h_d is depth of head of stud (EN1994-1-1:2004,Clause 6.6.5.7). For welded stud on top of flange of H steel beam, the diameter of welded stud should not exceed $1.5t_f$, where t_f is the thickness of the flange, and the spacing of shear stud should not be less than $5d$ in the direction of shear force and $2.5d$ in the transverse direction of shear force in solid slabs and $4d$ in other cases (EN1994-1-1:2004, Clause 6.6.5.7). The design shear resistance of headed stud should satisfy this expression:

$$P_{Rd} = \frac{0.8f_u\pi d^2/4}{\gamma_v} \quad (34)$$

Where f_u is the ultimate tensile strength of the material of stud not greater than $500N/mm^2$, d is the diameter of the shank of the stud, $16mm \leq d \leq 25mm$ and γ_v is the partial factor 1.25 (EN1994-1-1:2004, Clause 6.6.5.7)

2. Resistance of welded joints between H-steel beams and Rectangular hollow sectional tube columns

The design resistance of welded joints connecting H-steel beams to (rectangular hollow section (RHS) member is given in EN1993-1-8, Table 7.13)[33].The design internal axial force ($N_{1,Ed}$) should not exceed the design axial resistance ($N_{1,Rd}$) of welded joint $N_{1,Rd} > N_{1,Ed}$,

$$N_{1,Rd}=f_{y0}t_0(2t_1+10t_0)/\gamma_{M5} \quad (35)$$

$$M_{ip,1,Rd} = N_{1,Rd}(h_1 - t_1) \quad (36)$$

details are found in the Table 7.13 of EN1993-1-8,

4. Resistance of bolts in beam to column bolted connection

The design resistance of bolts in beam to column connection is given in EN1993-1-8, clause 3.1.1.(3). The yield strength (f_{yb}) and the ultimate tensile strength (f_{ub}) of bolts of classes: 4.6, 5.6, 6.8,8.8 and 10.9 are listed in Table 3.1 of EN1993-1-8. These values in Table 3.1 are taken as the characteristic values in calculations [33, 34].

a) When the bolts are in shear and tension

When the bolts are in shear, it should be designed as bearing type in category A(EN1993-1-8,clause 3.4.1(1)(a). When the bolts are in tension, it should be designed as non-preloaded in category D(EN1993-1-8,clause 3.4.2(1)(a), EN1993-1-8, Table 3.2,category of bolted connections.

The following formulas are adopted for both bolts in shear and tension resistance.

(i) For bolts in shear

$F_{v,Ed} \leq F_{v,Rd}$ and $F_{v,Ed} \leq F_{b,Rd}$,

(ii) For bolts in tension

$F_{t,Ed} \leq F_{t,Rd}$ and $F_{t,Ed} \leq B_{p,Rd}$,

b) Position of holes for bolts on the plate

According to EN1993-1-8, the minimum and maximum, end and end edges distances are provided as following:

Minimum end distance $e_1 = 1.2d_o$,maximum $e_1=4t+40mm$, where d_o is the diameter of hole and t is the thickness of the thinner outer connected part. Figure 13 shows the position of the holes.

Minimum end distance $e_2 = 1.2d_o$, maximum $e_2 = 4t + 40mm$.

Minimum spacing $p_1=2.2d_o$, maximum spacing $p_1=14t$ or $200mm$.

Minimum spacing $p_2= 2.4d_o$, maximum spacing $p_2=14t$ or $200mm$.

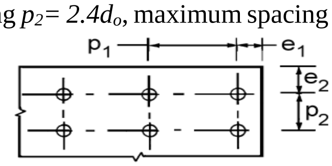


Figure 13. Position of hole for bolts [33].

c) Design resistance of bolt

Based on EN1993-1-8, Table 3.4, the formulas for design resistance of bolts in shear, tension and bearing are provided as following:

(i) Bolts in shear resistance

The shear resistance per shear plane can be obtained as:

$$F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}} \quad (37)$$

Where the shear plane passes through the threaded portion of the bolt (A is the tensile stress area of the bolt A_S).

$\alpha_v = 0.6$ for bolts of classes 4.6,5.6, and 8.8

$\alpha_v = 0.5$ for bolts of classes 4.8, 5.8,6.8,and 10.9

Where the shear plane passes through the unthreaded portion of the bolt (A is the gross cross section of the bolt) $\alpha_v = 0.6$

(ii) Bolt in tension resistance

$$F_{t,Rd} = \frac{k_2 f_{ub} A_S}{\gamma_{M2}} \quad (38)$$

Where $k_2=0.9$

$$B_{p,Rd} = 0.6\Pi d_m t_p f_u / \gamma_{M2} \quad (39)$$

$B_{p,Rd}$ is punching shear resistance , d_m is diameter of bolt, t_p is threaded height of bolt in plate and f_u is ultimate strength of bolt [35,36-38].

(iii) Bolt in bearing

$$F_{t,Rd} = \frac{k_1 \ \alpha_b f_u \ dt}{\gamma_{M2}} \quad (40)$$

Where α_b is the smallest of α_d , $\frac{f_{ub}}{f_u}$ or 1.0, d is the diameter of bolt ,t = threaded height of bolt In the direction of load transfer, for end bolts, $\alpha_d = \frac{e_1}{3d_o}$, $\alpha_d = \frac{P_1}{3d_o} - \frac{1}{4}$ for inner bolts Perpendicular to the direction of load transfer, For edges bolts, k_1 is the smallest of $2.8\frac{e_2}{d_o}$ -1.7 or 2.5 For inner bolts, k_1 is the smallest of $1.4\frac{P_2}{d_o}$ -1.7 or 2.5.For one bolt row in single lap joints, the design bearing resistance for each bolt should be limited to: $F_{b,Rd} \leq 1.5 \ f_u \ dt / \gamma_{M2}$.

4. Results and Discussions

4.1. Results of seismic analysis and design of four storied office novel precast prestressing composite frame

4.1.1. Establishment of the numerical model

The analysis and design was carried out using the above basic design steps and ETAB17 software for model building and internal forces calculation. The 3D model is shown in Figure 14 below. The results are validated with that one of four-storey building office of the developed novel structure constructed in Suzhou, China by ZYF Construction Group Co., Ltd. The novel structure has the floor plan dimensions of 63.6m×20.6m where ground floor height is 5.5m .and typical storey height is 4.2m. Bending moment diagram can be seen on Figure 15. The design parameters are shown in the Table 2, Table 3, and Table 4.

Table 2. Selected Materials properties according to African manner (EC2) and Chinese design system

Material properties	Values	
	African design system	Chinese design system
Unity weight of masonry	21kN/m^3	21kN/m^3
Unity weight of reinforced concrete	25kN/m^3	25kN/m^3
Grade of concrete	C35/C45 or f_{ck} =35	C40
Grade of rebar	B400	HRB 400
Grade of steel	S235, S355	Q235, Q355
Modulus of elasticity of concrete(*Ecm*)	34,000MPa	32,500MPa
Initial modulus of elasticity ($Ecm(t_o)$)	30,000MPa	-
Modulus of elasticity of steel	210,000 MPa	200,000MPa
Grade of prestressing steel(strand)	1860MPa	1860 MPa
Initial characteristic strength of concrete ($f_{ck}(t_o)$)	17.6MPa	26.8 MPa
Initial mean tensile strength of concrete($f_{ctm}(t_o)$)	2.8MPa	-
Mean tensile strength of concrete (f_{ctm})	3.2MPa	-
Tensile strength of concrete at transfer of prestress($f_{ct,0}$)	$f_{ct,0}=0.5f_{ctm}(t_o)$=1.4MPa	-
Compressive strength of concrete at transfer of prestress($f_{cc,0}$)	$f_{cc,0}$ = -0.5 $f_{ck}(t_o)$=-8.8MPa	-
Tensile strength of concrete after transfer of prestress($f_{ct,t}$)	$f_{ct,t}=0.5 f_{ctm}$=1.6 MPa	-
Compressive strength of concrete after transfer of prestress ($f$cc,t)	$f_{cc,t}$ = -0.5f_{ck} = -17.5MPa	-

Table 3. Load conditions according to African manner(EC1) and Chinese design system

Load conditions	Values	
	African design system	Chinese design system
Dead load	Self-weight of structural members	Self-weight of members
Live load for office(minimum)	2kN/m^2	2kN/m^2
Live load on roof	0.5kN/m^2	0.5kN/m^2
Plaster on floor	0.4kN/m^2	0.4kN/m^2
Floor tiles	0.45kN/m^2	0.45kN/m^2
Gypsum mortar under floor slab	0.36kN/m^2	0.36kN/m^2
Iron garvanized sheets	0.12kN/m^2	0.12kN/m^2
Truss	0.3kN/m^2	0.3kN/m^2
Purlins and system bracing	0.1kN/m^2	0.1kN/m^2
Gypsum ceiling	0.1kN/m^2	0.1kN/m^2

Table 4. Earthquake parameters

	African design system	Chinese design system
Location	Southern Province of Rwanda, Huye City	Suzhou, China
Seismic zone(earthquake level or intensity)	VI with PGA *0.10g*	7 with PGA *0.10g*
Earth quake design group	-	1
Ground type(Site class)	Type C	Site class II
Importance factor	1	-
Time period(Vibration period)T	$T= C_tH^{3/4}$ C_t = 0.05, *H=18.1m T=0.44s*	*0.45s*
Earthquake load direction	*X* and *Y* direction	*X* and *Y* direction
Diaphragm type	Rigid	Rigid
Type of analysis	Linear Static	Linear Static

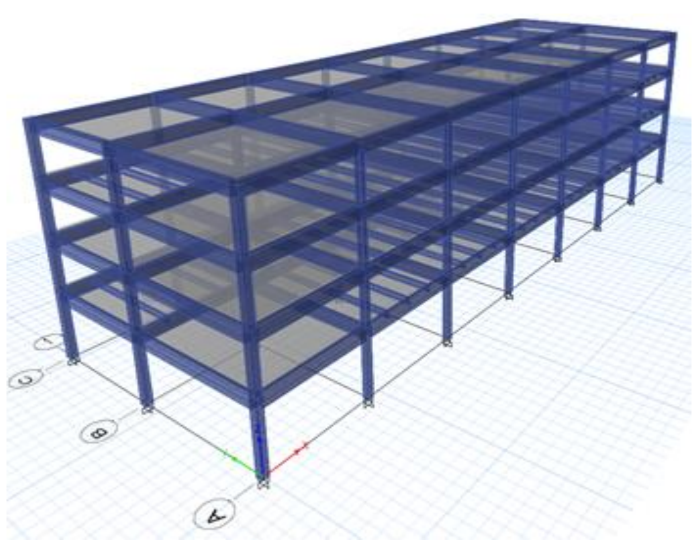


Figure 14. 3D View of the model in ETABS software

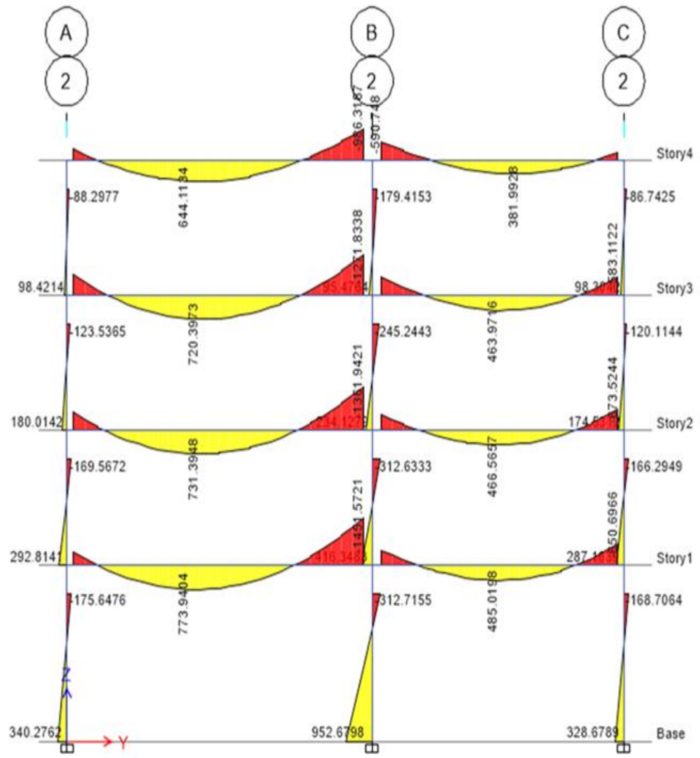


Figure 15. Bending moment diagram

4.1.2. Design results

After the analysis and design using basic design steps and EABS17 software, the following Table 5 shows the detail design results which were validated with that one of four-storey building office of the developed novel structure constructed in Suzhou, China by ZYF Construction Group Co., Ltd.

Table 5 Validation of detail design results

Structural member	African design system	Chinese design system
Precast prestressed slab	160mm thick,80mm in situ casting,5strands 12.7mm each flat duct, overall thickness of composite slab=240mm	140mm thick,100mm in situ casting,3 strands each flat duct, overall thickness of composite slab=240mm
Precast prestressed beam mid-span	h=900mm,b_W=400mm,A_S top=5T25,A_S btm=3T25, 5strands 12.7mm,	h=900mm,b_W=400mm,A_S top=7T20,A_S btm=5T20, 3strands 12.7mm,
End of beam connection with H-steel beam	H700x300x13x24mm	H700x300x12x18mm, H800x300x12x18mm
Concrete filled rectangular steel tube columns	External columns 650X550mm(550x450x20mm) Internal columns 850X750mm(750x650x24mm)	External columns 650x550mm(550x450x16mm) Internal columns 600x500mm(500x400x16mm)
HSB(High Strength Bolt)	M27	M22

According to Table 5, the design results from African design system are greater than that ones in Chinese design system. For instance, the web and flange thickness of H-steel beam section are greater than that ones in Chinese design system but, the height and width are the same. This means that more steel is used in African design system, and the African design system is more conservative while Chinese design system is more economical. In addition, the safety factor for dead load and live load in African design code is greater than that in Chinese design code.

Regarding design of prestressed members, the African design code use more strands and greater section thickness than the Chinese design code, however the grade of strand is the same.

The ETABS 17 software was employed to assess the seismic loads effects in both African and Chinese design system, and the results are summarized in the tables and figures below.

Table 6. Comparison of the seismic actions

Chinese Design system		African design system		
Storey	*Fi(kN)*	Storey	*Fi(kN)*	%difference
1	512.62	1	529.78	2.673
2	892.79	2	912.24	2.132
3	1279.35	3	1307.37	2.143
4	1309.92	4	1328.37	1.389
			Average	2.1

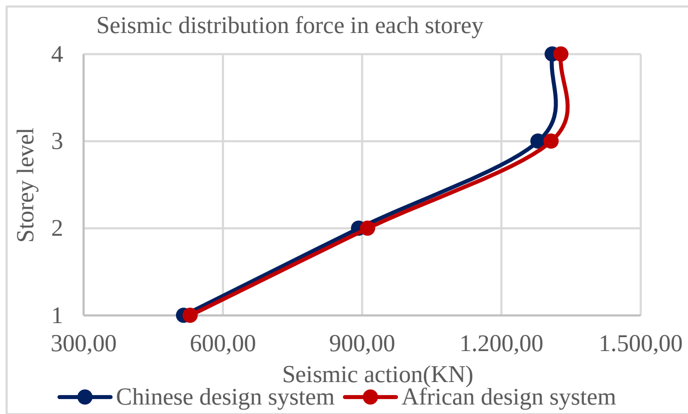


Figure 16. Seismic distribution force in each storey

From analysis done, comparing the seismic base shear or the expected lateral force on the base of the building structure due to seismic loads, it is found that F_{Ek} =4,054.47kN in Chinese design system is less than F_b = 4,077.53kN in African design system. This is due to the fact that the seismic map of Rwanda, where the site is located with earthquake intensity of 6 with PGA 0.10g is close to that one in Chinese system which is 7(0.10g), but have different design spectrum such as $S_d(T_1)$ = 0.0871g for African method and αmax=0.08 for Chinese method[39,40].

The seismic force in each storey in African design system is greater than that one in Chinese design system by average 2.1%, as indicated in Table 6. Therefore, this indicates that the African design system considers the building structure to resist much applied earthquake forces more than Chinese design system and it is more conservative. Figure 16 shows the curves which indicate the trends of seismic force distribution in each storey. For both design systems, the curves show the increase of seismic force with the height of the building. Therefore, the higher the building is, the greater the earthquake effect is, and in multistorey building design, earthquake effect should be highly considered and especially in high seismic zones, more precaution have to be provided.

Table 7. Max interstorey drift in *X* direction due to earthquake

Chinese Design system		African design system		
Storey	Drift (%)	Storey	Drift (%)	%difference
1	0.0533	1	0.0544	2.0
2	0.0522	2	0.0551	5.3
3	0.0391	3	0.0411	4.9
4	0.0228	4	0.0229	0.4
			Average	3.1

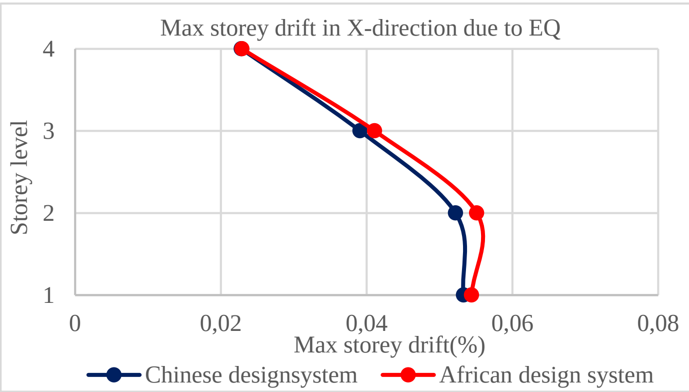


Figure 17. Max interstorey drift in *X*-direction due to earthquake

Table 8. Max interstorey drift in *Y*-direction due to earthquake

Chinese Design system		African design system		
Storey	Drift (%)	Storey	Drift (%)	%difference
1	0.0584	1	0.0608	3.9
2	0.0598	2	0.0626	4.5
3	0.0457	3	0.0468	2.4
4	0.0278	4	0.0285	2.5
			Average	3.3

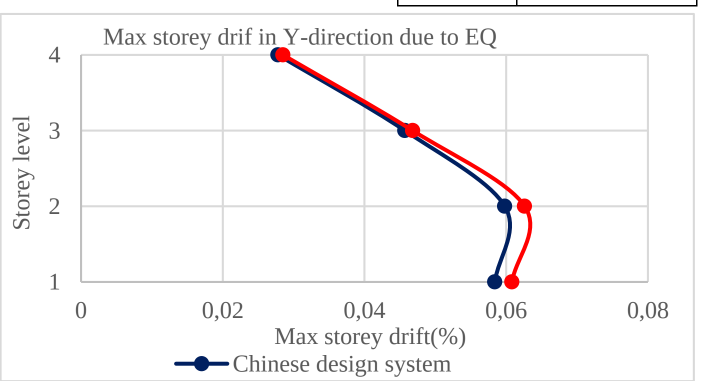


Figure 18. Max interstorey drift in *Y*-direction due to earthquake

Storey drift is the horizontal displacement of the floor relative to the floor below. In Figure 17 and Table 7 above, the max storey drift due to earthquake in *X*-direction under Chinese design system is average 3.1% lower than that in African design system, and in *Y*-direction in Figure 18 and Table 8, the Chinese design system is average 3.3 % lower than that in African design system. This indicates that the Chinese design system takes into account the earthquake loads effect at higher level than it is in African design system. In addition, both design systems are safe since the results of storey drift do not exceed the maximum allowable limits, and the drift ratio (%) in each storey are less than 0.5% ,which indicate that after the earthquake the building is repairable.

5. Conclusions

As Chinese construction companies remain entering Africa continuously to carry out construction projects in different African countries in line with sustainable development, the developed construction method in China are most likely to be applied in the old continent. A novel precast prestressing composite structure, developed by Chinese investigators and constructed by ZYF Company in Suzhou, China, is believed to have a good prospect in Africa. Therefore, this study aimed to design method of the mentioned novel precast structures based on African manners to help Chinese construction companies to design and implement the novel precast structures in Africa. The work and conclusions of this study are as follows:

1. The structural design systems in Africa and China was compared to help designers know the difference between the two design system and develop a better design method for the new precast prestressed composite frame in Africa. The structural design system in Africa is based on Eurocodes, therefore, main Eurocodes were selected for the comparison. The comparison included material properties, loads and load combination, design equations for composite elements. It can be found that the basic theory of the two design system is similar, but the technical design parameters and equations are different, thus, it is necessary to develop a structural method based on African manners for the novel precast structure.
2. The structural design method of the novel precast structure was built with African design system. The basic structural design steps based on the limit state method according to Eurocodes were established, and the seismic design process for the novel precast structure was also developed based on equivalent lateral seismic force method. Some important structural details of the novel frame for earthquakes based on African manner were presented.
3. The developed detailed design method of the novel structurewas applied by designing a four storey novel building structure expected in Huye City at Southern Province of Rwanda, of which the earthquake parameters were close to the ones of Suzhou, China. The design results were validated by comparison with results of the novel four storey building structure constructed in Suzhou, China. The strengths of connection between the H-steel beam to concrete filled rectangular steel tube and between H-steel beam and precast concrete portion, were verified using the recommended formula from the previous experimental investigation [11] and fulfilled the conditions and requirements.

Considering earthquake loads in design, the max interstorey drift ratio is 0.0626% in African design system and 0.0598% in Chinese design system. The interstorey drift in the Chinese design system, is on average 3.3% lower than that in African design system. The main difference of the determined structural details is that structural H-steel beam profile section found in African manners have greater web and flange thickness than that in Chinese design system. The size of concrete filled rectangular steel tube used in African design system is greater than that one used in Chinese design system. Hence, it is shown that both design systems provide safe design since all the results are within allowable limit, and the Chinese design method is more economical but the African design method is more conservative.

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Conflict of Interest Statement

The author declares that there is no conflicts of interest concerning this article.

References

1. Lucy Corkin. (2011).Chinese Construction Companies in Angola: A Local Linkages Perspective.MMCP Discussion Paper No 2, University of Cape Town and Open University, ISBN: 978-1-77011-233-9.
2. Ian Taylor and Tim Zajontz. (2020). In a fix: Africa's place in the Belt and Road Initiative and the reproduction of dependency. South African Journal of International Affairs, VOL.27, NO.3,277–295. https://doi.org/10.1080/10220461.2020.1830165
3. Chuan Chen. (2007). An empirical analysis of Chinese construction firms' entry into Africa. The CRIOCM2007 International Symposium on Advancement of Construction Management and Real Estate 8-13, Sydney Australia.
4. Christopher Burke. (2007). China's Entry into Construction Industries in Africa: Tanzania and Zambia as Case Studies. CHINA REPORT 43 : 3 :323–336 SAGE Publications Los Angeles/London/NewDelhi/SingaporeDOI: 10.1177/000944550704300304
5. Tim Zajontz. (2020). The Chinese infrastructural fix in Africa: Lessons from the Sino-Zambian 'road bonanza'. Oxford Development Studies, DOI:10.1080/13600818.2020.1861230
6. Chuan Chen and Ryan J.Orr.(2009). Chinese contractors in Africa: home Government support, coordination mechanisms, and market entry strategies. Journal of construction engineering and management, 135(11):1201-1210.
7. Chuan CHEN et al, local operations of Chinese construction firms in Africa: an empirical survey [J]. The International Journal of Construction Management (2009) 75 – 89
8. Bungale.S. Taranath, ph.D, P.E, S.E. (2017). Tall building design, steel, concrete, and composite system.
9. Rui Li.(2016). Seismic properties of joints composed of CFST columns RBS composite beams, PhD thesis. Australia, Institute of infrastructure Engineering Kingswood Campus Penrith NSW Australia Western Sydney University.
10. EN1994-1-1-Eurocode4. (2004).Design of composite steel and concrete structures part1.1General rules and rules for buildings.
11. Shuaike,F.,Donghzi,G.,Zhengxing,G,,Zhongxiang,L.,Guojian,L., Changyi,G.(2021). Seismic performance of assembly joints between HSPC Beams and concrete-encased CFST Columns. Journal of Construction steel Research 180,106572 P.1-14.
12. Zhang, X., Zhang, S., Niu, S. (2018). Experimental studies on seismic behavior of precast hybrid steel–concrete beam. Advances in Structural Engineering, 00(0): 1–17.
13. Shuaike, F., Donghzi, G., Luyao, N., Yu, L., Zhongxiang, L., Zhengxing, G. (2022). Experimental study on seismic behavior of joints connecting precast H-steel reinforced concrete beams and concrete-filled steel tube columns.Journal of building engineering 4,103444 P.1-15.
14. Li, B., Kulkarni, S., Leong, C. (2009). Seismic performance of precast hybrid-steel concrete connections. Journal of Earthquake Engineering, 13(5): 667-89.
15. MIDIMAR (2015). The National Risk Atlas of Rwanda.
16. Erochko, J., Christopoulos, C., Tremblay.R, Choi, H. (2011). Residual drift response of SMRFs and BRB frames in steel buildings designed according to ASCE 7-05. Journal of Structural Engineering (ASCE), 137(5): 589-99.
17. R.P.Johnson. (2004). Composite structures of steel and concrete.
18. R.Narayanan. (2005). Steel-concrete composite structures stability and strength.
19. Anamika Tedia and Dr. Savita Maru. (2014). Cost, Analysis and Design of Steel-Concrete Composite Structure Rcc Structure". IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 11, Issue 1 Ver. II, PP 54-59.
20. Jianguo NIE.,Jiaji WANG.,Shuangke GOU.,Yaoyu ZHU.,Jiansheng FAN.(2019). Technological development and engineering applications of novel steel-concrete composite structures. Front. Struct. Civ. Eng., 13(1): 1–14 https://doi.org/10.1007/s11709-019-0514-x
21. Alessandro, Z., Michele, B., Joel, P.Conte, M.ASCE. (2008). Nonlinear seismic response analysis of steel-concrete composite frames.Journal of structural engineering, P.986-997.
22. Enrico Spacone, A.M.ASCE., Sherif EI-Tawil, M.ASCE. (2004).Nonlinear analysis of steel-concrete composite structures: State of the arts.Journal of structural engineering Vol.130, No.2, P.159-168.
23. Raymond, I.G., Neil Colin M., Gianluca R. (2017).Design of prestressed concrete to Eurocode2, second edition.
24. Yang K, Oh M，Kim M. (2010). Flexural behavior of hybrid precast concrete beams with H-steel beams at both ends. Engineering Structures, 32(9): 2940-49.
25. Yang K, Seo E, Hong S. (2016). Cyclic flexural tests of hybrid steel-precast concrete beams with simple connection elements. Engineering Structures, 118: 344-56.
26. Kim S.Elliot. (2017). Precast concrete structures second edition.
27. GB50009-2001. (2002). Load code for the design of building structures, Ministry of construction of the People's Republic of China, Beijing.
28. GB50017-2003. (2003). Code for design of steel structures, Ministry of construction of the People's Republic of China, Beijing.
29. Yida Guo., Guobin Gong., Chee Chin., Cheng Zhang. (2018). Structural design of concrete to EC2 and GB50010-2010: a Comparison. MATEC Web of Conference, 175, 01039, pp.1-851.
30. JGJ138-2016. (2016).Code for design of composite structures, Ministry of housing and Urban-Rural development of the People's Republic of China, Beijing.
31. EN1992-1-1-Eurocode2. (2004). Design of concrete structures part1-1, general rules and rules for buildings.
32. BSI, Steel, concrete and composite bridges BS5400: Part 5. (1979).Code of practice for design of composite bridges.

33. EN1993-1-8-Eurocode3. (2003). Design of steel structures part1-8, design of joints.
34. EN1993-1-1-Eurocode3. (2003).Design of steel structures part1-1, general rules and rules for building.
35. EN1991-1-Eurocode1. (2001).Actions on structurespart-1-1, general actions, densities, selfweight, imposed loads for building.
36. EN1990-1-Eurocode0. (2001). Basic of structural design.
37. W.H.Mosley, R.Hulse, J.H.Bungey. (2012).Reinforced concrete design: to Eurocode 2.
38. BSI, Structural use of concrete. Part I:(1997) Code of practice for design and construction.
39. GB50011-2010. (2014). Code for seismic design of buildings, China Architecture and Building Press, Beijing.
40. EN1998-1, Eurocode8. (2003). Design of structures for earthquake resisntantce-Part1: General rules, seismic actions and rules for builings.