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Economic Optimization Mathematical Model of the Public Building Canopy Structure

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Abstract: The purpose of this study is to study the impact of public buildings architecture on the project investment. Economic optimization analysis is given by specific values. The finite element analysis of 216 beams is completed and the project amount of six kinds of structure under the three types of load and 12 kinds of span are analyzed. Then, the impacts of the parameters are presented and the best scope of each structure is come out. The final economic contrast results provide reference and recommendations for the design and inspection of the public buildings floor structure.

Key words: Optimization, mathematical model, public building, conceptual analysis

INTRODUCTION

The mechanical property of the public buildings has always been one of hot spots in the field of structural research. Its structural performance and cost optimization is the research interest of many researchers (Zhigang and Chaohe, 2011). By the analysis of six kinds of floor structure program, Yang *et al.* (2008) gave its technical and economic indicators. Liu *et al.* (2011) found that the Economic effect is significant. Economic analysis was made on the pre stressed structural system of secondary beams and slabs of large span. From the analysis of commonly used floor systems, some researchers take the following factor as the main economic and technical indicators for the various systems, such as the material usage, cost, structure height and deflection (Corgnale *et al.*, 2012; Frye and Morris, 1975). Along with the engineering practices, the techno-economic analysis is discussed. By comparison of the amount and cost of the project, the economic performance of the structure was studied under different conditions and a complete structure solution was given (Dolomanov *et al.*, 2009). Cheng and Wang (2009) made economic comparison of the ribs on the wide flat beam and girder floor system. To simplify model, common column grid size was established (Jaboyedoff *et al.*, 2009; Bommes *et al.*, 2011) and a comparative analysis was done about the flat floor slab and the beam-slab floor (As'habi *et al.*, 2008). Moreover, a comparative economic analysis of a thin shell plastic is given by Babur O. and Ibrahim S. (2009).

Under different loading conditions, a reasonable selection of structure terms plays an important role for investment control (Diaaz and Kikuchi, 1992). Taking the floor load and span factors into account, the floor structures is studied mainly from the point of economic, or the project amount.

STRUCTURAL CONCEPTUAL ANALYSIS

Factors including the structure, construction and maintenance, the macro-economic aspects and so on, impact on the major economy of floor structure. From the point of structural concept mainly, the economic impact on floor structure of public buildings of various factors is analyzed, including the choice of the span, load, structure choice, high-span ratio, aspect ratio, stiffness requirements, strength grade of concrete and reinforced steel grade.

This study studies the impact of span, load and structure on the economy, so other factors must be controlled or limited unchanged, according to Code for the design of concrete structures in China (GB50010-2002) and Code for the design of steel structures (GB50017-2003), to determine the design conditions of floor beams: reinforced concrete beam (RC-beam) and steel reinforced concrete beam (SRC-beam) which are selected C30 concrete, prestressed concrete beam (PRC-beam) selecting C40 concrete, with longitudinal reinforcement HRB335, with stirrups HPB235, with Q345 steel, steel tendons using strand 1860. The largest deflection of beam is controlled to L/400.

Six kinds of structure as RC-beam, PRC-beam, SRC-beam, solid-web steel beam, plane truss beam and space composite truss beam are analyzed separately. Three sizes of load (36, 72 and 144kN/m) are involved in comparative analysis. In order to facilitate the comparative analysis, identify the following principle of simplicity: according to the features of floor of public building, it is simplified into a freely supported beam whose span is from 9 to 42 m by the module of 3 m, only considering the static load and its weight on the floor is converted into line load which is loaded on freely supported beam. In practical engineering, with reliable connection of floor

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beams and floor, without checking its lateral stability, so the stable problem of the beam is no longer considered.

CONTENTS AND PROCEDURES

Research contents: The main research contents of the economic conceptual analysis of the public building floor include the following: (a) According to the analysis of the size and material parameters of the six kinds of structure, we can obtain the statistics data of the amount of concrete and steel construction under various structural forms in a variety of loads and various span.13 variables are defined from point of view of the engineering cost to make a comparison of economic analysis. (b) According to economic indicators, a concrete equivalent amount to economic value of the project is converted

Interpretative structural model of canopy structures: In this section, the logical relationship of canopy structure design parameters is given using the Interpretative Structural Model method (Kannan *et al*., 2009).

In general, four steps (Chidambaranathan *et al*., 2009; Sahney *et al*., 2010) are included in the specific process of interpretative structural modeling analysis of the logical relations. (a) According to the analysis object, the main parameters within a complex system are selected out (Xiao *et al*., 2009); (b) using the relationship between the main parameters, the adjacency matrix is presented and then reachability matrix can be obtained by matrix operations; (c) direct and indirect relationships between all the system parameters can be drawn up and (d) the connection diagram and logic level relationship of the major parameters are obtained finally.

The optimize target of the canopy structure is set to the minimum amount of structural steel. By ISM Analysis method, the relationship between design parameters and economic indicators of the canopy structure system are discussed. According to different degree of influence to the amount of structural steel, all design parameters are grouped to several logical levels, which are called the establishment of a logical hierarchical relationship. The following is a detail process of logic-level relationship analysis.

Selecting the design parameters of the canopy to optimize the system: 12 parameters are selected from all the design parameters of the most influential on the steel amount of canopy and sort out their relationship by mutual restraint and influence, which are shown in Table 1.

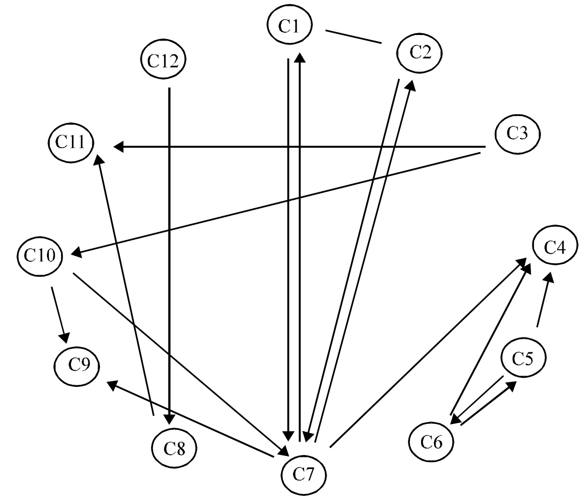

Fig.1: Connection diagram of design parameters

Table 1: Parameters relationship by mutual restraint and influence

Code	Design parameter	Direct influence parameter
C1	Canopy structure type	C2,C7
C2	Station type	C7
C3	The scale of the station house (total area)	none
C4	Climatic conditions 1 (the basic wind pressure)	C5,C6,C7
C5	Climatic conditions 2 (the basic snow pressure)	C6
C6	Climatic conditions 3 (temperature section)	C5
C7	Basic column grid	C1,C2,C10
C8	Seismic intensity	C12
C9	Strength of the material	C10,C7
C10	Individual size (projected area)	C3
C11	Storey (height of canopy)	C3,C8
C12	Site soil category	Non

Drawing the connection diagram of the design parameters of canopy structures: According to the mutual relations among the parameters in Table 1, the connection diagram can be obtained (Fig. 1), in which, "X-->Y" means that parameter X affected or restricted parameters Y.

To determine the logic level relationship of design parameters of canopy structures: The step of determining the logic level relationship of the design parameters are computed with Matlab programming.

According to the interpretative structural modeling analysis, the greater the impact on the target index (the steel amount of canopy structure), the higher level the design parameters in level logic diagram. As shown in Fig. 2, in the technical parameters of the structure, changing some parameters may cause great changes in one or more design parameters and ultimately significantly affect the amount of steel.

Analysis showed that the climatic conditions (the basic wind pressure) C4, the strength of the material C9 and storey (height of canopy) C11, are all in the first level.

At the same time, canopy structure type C1, station type C2, climate conditions 2 (the basic snow pressure) C5, climatic conditions 3 (temperature section) C6, the basic column grid C7 and seismic fortification intensity C8 in the second level.

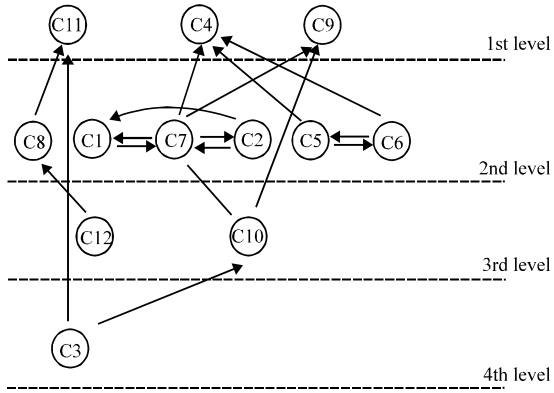

Fig. 2: Logic level relationship of design parameters

Finite element model of the structure: The parameters, C9 and C11 in the first level and C2 in the second level, are selected by the project specific functional requirements of materials and construction decisions, usually, which cannot be changed in the structural design process. Therefore, in the canopy economic concept analysis, the basic wind pressure C4, structure type C1, the basic column grid C7 and seismic intensity C8 are taken as the main parameters, which are major factors in the optimization of canopy structure.

The values of the main parameters are as follows: the basic wind pressure is 0.3, 0.4 and 0.5 kN m^{-2} representatively; structure type are shown in Fig. 3 to5;

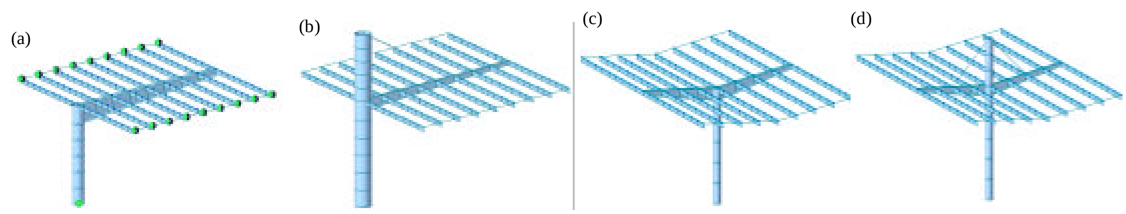

Fig. 3(a-d): Solid web canopy structures, (a) Unilateral cantilever, (b) Unilateral with rod, (c) Bilateral cantilever and (d) bilateral with rod

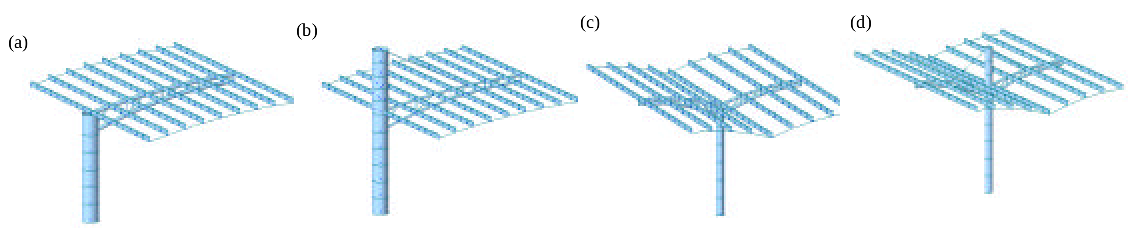

Fig. 4(a-d): Plane truss canopy structures, (a) Unilateral cantilever, (b) Unilateral with rod, (c) Bilateral cantilever and (d) bilateral with rod

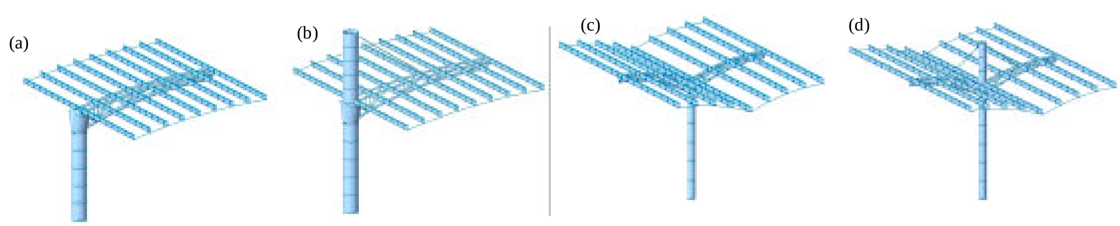

Fig. 5(a-d): Space truss canopy structures, (a) Unilateral cantilever, (b) Unilateral with rod, (c) Bilateral cantilever and (d) bilateral with rod

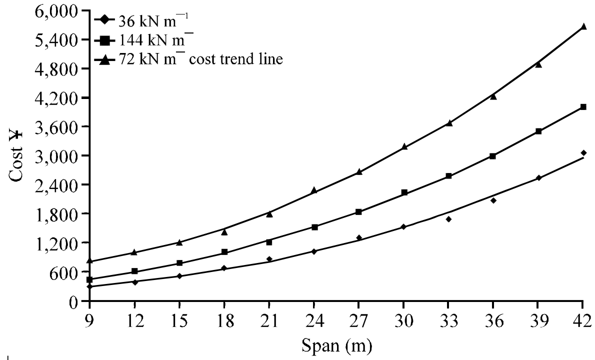

Fig. 6: Cost curve of RC-beam

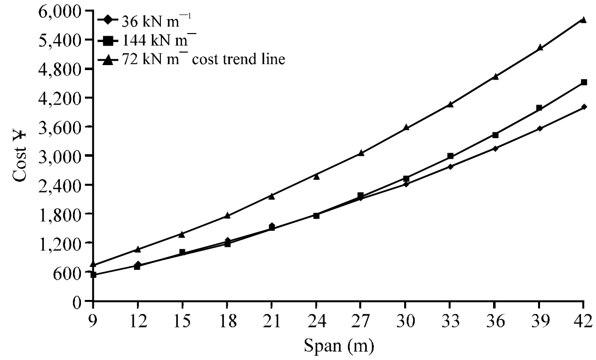

Fig.7: Cost curve of PRC-beam

basic column span is determined as 12, 15 and 18 m; three levels of seismic intensity are taken into account, seismic acceleration are 0.05, 0.1 and 0.2 g, respectively.

Displacement controls are based on the current specification standard. Capitals level of displacement (under wind load standard value) is less than or equal to the $H_0/400$ (where, H_0 is calculated height of columns). The value for main beams changes to $L_0/200$ under dead load and live load standard value (where, L_0 is calculated length of the beams).

The skin effect and the space the overall impact are ignored during simplification of canopy structure model. Model's boundary conditions changed into symmetrical bearing in the normal plane of the purlin axis. Considering the actual stress state because of the canopy pole and tied, the weak axis instability problems are not taken into account.

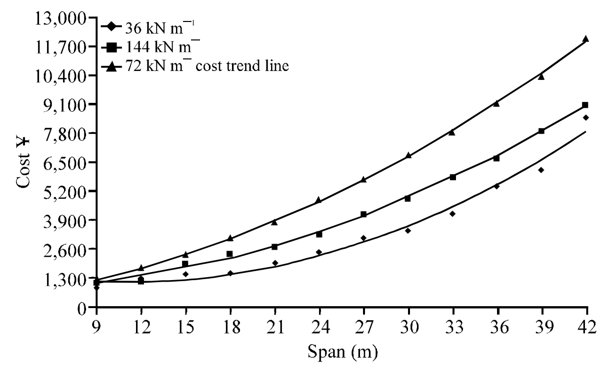

Fig. 8: Cost curve of SRC-beam

DATA STATISTIC ANALYSIS

Based on the finite element analysis results, we get every variable value of various structural forms, respectively, by counting and calculating data from model analyzing. Then we divide the six kinds of structure into two groups for comparative analysis. So, we can obtain the economic impact of every factor.

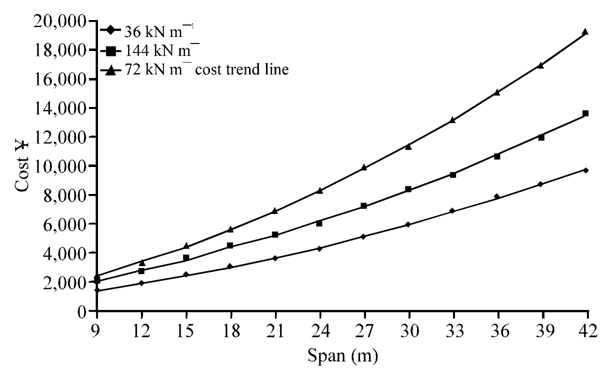

Fig. 9: Cost curve of solid-web steel beam

Economy analysis of concrete structure floor: According to the project amount of three sizes of load and the economic indicators, we can obtain the cost of RC-beam, PRC-beam and SRC-beam. Then fit these cost point into the curves as shown in Fig. 6 to 8. According to the contrastive analysis of per three curves for every kind of structure, we find that the cost curve of PRC-beam under 36 and 72 kN m^{-1} are too near when the span is less than 27m, so we can say that PRC-beam is not applied to small load, or when the load is small we should not choose PRC-beam firstly.

Economy analysis of steel structure floor: Also we can obtain the cost of Solid-web Steel-beam, plane truss beam and space composite truss beam. Then fit these cost point into the curves as shown in Fig. 9 to 11. According to the contrastive analysis of per three curves for every kind of structure, we find that to the same span the increment of cost of Solid-web Steel beam with the load increase before 24 m is different from it after 24 m.The forward value is negative but the back value is positive. To the same span the increment of cost of truss beam increase with the load increase.

Table 2: Cost table of every meter

Span (m)	Reference range of cost/structural style recommend (RMB m^{-1}) 36 kN m^{-1}		72 kN m^{-1}		144 kN m^{-1}	
9	318~846	Reinforced concrete beam	450~1050	Reinforced concrete beam	849~1226	Reinforced concrete beam
12	375~1218		612~1143		1054~1757	Prestressed reinforced concrete beam
15	516~1445		987~1962	Prestressed reinforced concrete beam	1359~2292	
18	1237~1508	Prestressed reinforced	1144~2371		1738~3100	
21	1539~1979	concrete beam	1513~2656		2131~3814	
24	1745~2419		1706~3220		2541~4802	
27	3085~3610	Plane truss beam	4154~4805	Steel reinforced concrete beam	5695~7410	Steel reinforced concrete beam
30	3418~4016		4883~5385		6786~8013	
33	3948~4474		5817~6935	Plane truss beam	7842~9316	
36	4291~4964		6581~7601		9115~9953	
39	4665~5509		7234~8538		10928~13326	Plane truss beam
42	5065~6087		7881~9113		12022~14095	

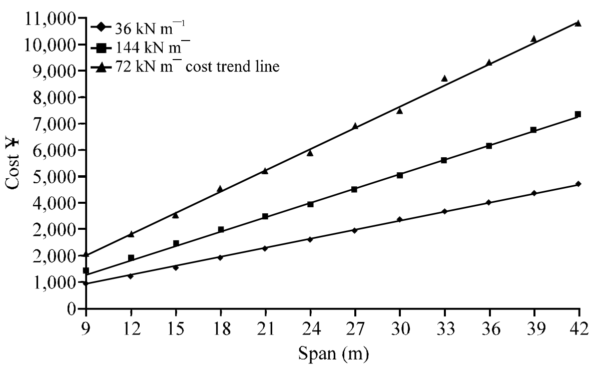

Fig. 10: Cost curve of plane truss beam

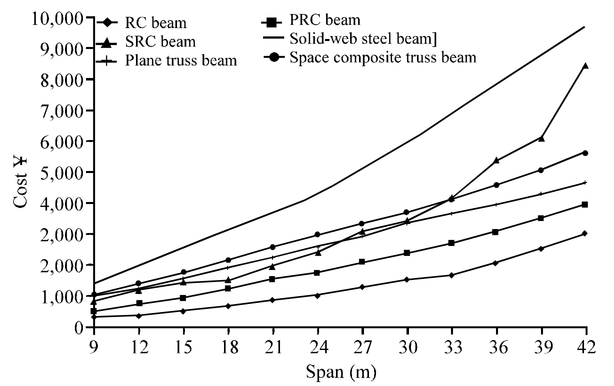

Fig. 12: Cost under the load of 36 kN m^{-1}

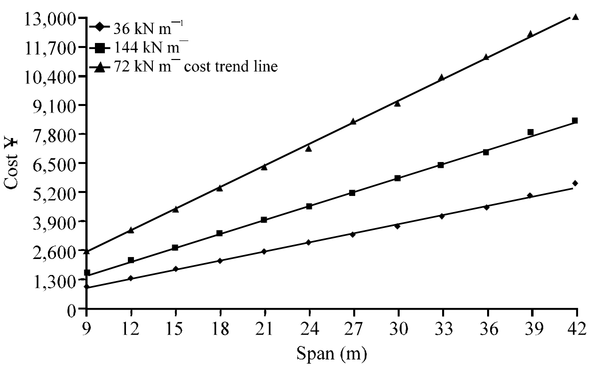

Fig. 11: Cost curve of space composite truss beam

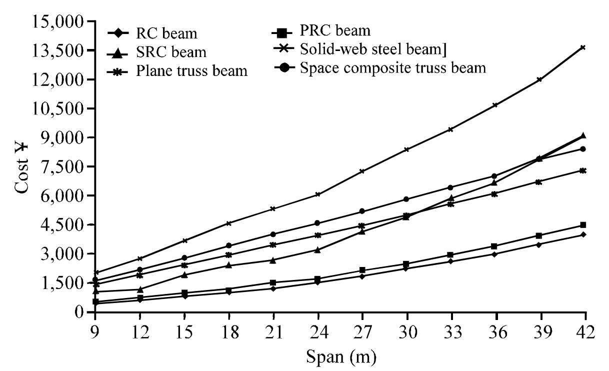

Fig. 13: Cost under the load of 72 kN m^{-1}

Comparative analysis of approximate cost: The prices are converted to economic indicators by the price of concrete per cubic meter. Then the cost of six kinds of structure under three sizes of load can be calculated by the project amount and the economic indicators and the curves can be drew as Fig. 12 to 13.

Reference range of cost and structural style recommend listed in Table 2.

CONCLUSION

By comparative analysis of six kinds of structure, it was found that every structure has its own conditions for application and variation tendency of ACM and ASM at different span reflects more obvious. The advantages of different structure also change as the load changing.

First,with the load increasing, ASM and ACM of the same structure increase continually under the same span. The increment of project amount of the same structure is almost unchanged when the load increases by one time. With the span increasing, ASM and ACM of the same structure increase under the same load and its changing degree and trend of every structure are different. With the structure changing, ASM and ACM are different under the same load and the same span.

Second,with the increase of span ,the variation of ISM of truss beam is small and the variation of ISM of solid-web steel beam is different when the spans are Greater than 24 m and less than 24 m and the increment of project amount of the three concrete structures continually increases.

Third, Truss beam and Solid-web Steel beam are applied to various spans, but the manufacturing process of truss beam is too much trouble, so we can choose other structures for the span of less than 15 m and we can choose PRC-beam or SRC-beam first for the span of 15-27 m, but when the load is small we should avoid choosing PRC-beam and we should give priority to PC-beam when the span is less than 15 m.

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