FROM PRE-CASTING TO COMPOSITE METHOD IN AUTOMATION OF BUILDING CONSTRUCTION

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SUMMARY

The characteristics of industrialization are lower costs, mass production, considerable use of machinery and labor saving. The idea of pre-casting evolved from constructing building structures through industrialized sequences. Each segment is to be manufactured in factories with standard procedures and assembled on site to save manpower. Tying reinforcing bars is undoubtedly an indispensable procedure in concrete structure construction. Rising technologies have brought this work to many solutions, such as the adoption of welded wire fabric. Despite the achievements of industrialization of construction, there are still not sufficient solutions to satisfy various needs in housing construction. More efforts shall be spent to develop the best "composite method", which combines and integrates various technologies for building construction.

INTRODUCTION

The industrial revolution began in middle of 18th century. It successfully reduced costs and manpower through mass production and the use of machinery. In the age of knowledge economic and information technology, the normalized construction could not satisfy the clients' needs. The development of future construction requires brain storming to create more possibilities. Current tendency of building construction is to seek the best "composite solution" combining the optimization among construction methods, management, information technology and materials to fulfill individual requests.

Installing reinforcement steel is for sure an indispensable procedure in construction of reinforced concrete. Being refined in its development toward the industrialized standard, several technologies of the field have proved the successful outcome. For example, the applications on welded wire fabric in structure elements such as columns and beams are increasing profoundly. While the ever-improving technology has drastically decreased the labor cost for steel bar bending and tying, it also standardizes bar spacing and, at the same time, improved the quality. Moreover, there are a few cases of successful automatic steel bar cages assembling and several brilliant R&D ideas are now flourishing from it. The aim of

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the automation is to cut down the labor cost of steel bar assembling by 80 % or more.

More efforts should be devoted to development of the best “composite method” that integrates construction, managerial, computer, and material technologies for building construction. One convincing example in applying advanced construction methods is the construction of anti-ambient-vibration floors in wafer factories. Using the new method of semi-precasting in constructing waffle slabs in a wafer factory can effectively reduce the weight of the slabs to facilitate the construction process (from production, shipping, lifting, to assembling of the slabs). The construction period can be dramatically shortened by six month in this case. Moreover, the anti-vibration performance of this composite method has also been verified by the experts and proved to be as good as that of the traditional method.

In addition to the advancement on construction methods, progress has been made on development of novel management and information technologies. The concept of “Concurrent Engineering” has been introduced into the field building construction. It depends heavily on meticulous pre-planning and self-criticizing for a successful outcome. As we know well, most of cost down by value engineering should be done before real constructing works proceeds. The key issue is what kind of tools we apply to figure out any conflict as soon as possible. By the way, three-dimensional computer-aided tools have allowed for spatial simulations on architecture, structure, and electrical and mechanical equipments in building construction. The tools can also be used together with the scheduling software to review the construction sequences in 4-D.

On the advancement of material technology, high strength concrete has been intensively researched and developed. In practice, there has been application of 700 kg/cm^2 (10,000 psi) concrete. Other than the structural construction materials, concrete placement is as well having a profound improvement. With the technology being advanced now, stability of materials can be maintained through dry mix materials and the mix proportion can also be standardized. With special chemical admixture added in, concrete becomes more workable and the skill requirements for concrete placement are lowered, respectively. It all promotes the quality of construction on plastering works such as, mortar bed application, finishing and tile installation. Special demands can also be met by providing special formulated concrete

	date	91/02/08	91/02/18	91/03/07	91/03/11	91/03/14
items	steps	Trandi tional way	First Generation	Second Generation	Third Generation	Forth Generation
	workers	Taiwan worker	Thai worker	Thai worker	Thai worker	Thai worker
I	adjust hooks					
	set hooks	15'x2=30'	8' x2=16'	5'55"x2=11'40"	3'43"x2=7'26"	3'25"x2=6'50"
	erect hooks					
II	put rebar	8分x2=16分	9' x2=18'	8'40"x2=17'20"	6'4"x2=12'8"	4'x2=8'
	fix rebar	1.5'x2=3'	80"x2=2' 40"	1'15"x2=2'30"	1'27"x2=2'54"	2'x2=4'
III	move hooks	3'x2=6'	230"x2=7' 40"	3'45"x2=7'30"	6'13"x2=12'26"	3'30"x2=7'
IV	tie hooks	20'x2=40'	35' x2=70'	31'45"x2=63'30"	24'35"x2=49'10"	21'30"x2=43'
	put cross ties	44'x2=88'				
	tie cross ties	33'x2=66'				
time(min,sec)		263'	114' 20"	102'40"	82'4"	68'50"
weight per sets(t)		0.825288	0.79348	0.79348	0.76348	0.76348
rate (hr/t)		5.31	2.40	2.16	1.79	1.50
percentage(%)		100%	45%	41%	34%	28%

Table 1 Recently working rate improvement for steel rebar cage assembling

like, self-compact concrete, wearing-resistant concrete, light-weight concrete, heavy-weight concrete, and etc.

CASES OF INDUSTRIZATION

The concept of pre-cast construction methods was evolved from the industrialized manufacturing processes. The general idea is to divide a structure into several structural elements, which are to be produced following standardized sequences in a factory and assembled on site. Customized steel moulds are adopted for the production of each element. Besides, the production requires less manpower. Concrete is poured and cured in an environment we could control so as to assure that the qualities of those elements are conformed to the design requirements. When the idea of pre-cast enters into many links of manufacture processes, it is not only able to reduce the cost but to build with construction methods which are more precise and convenient. Listed below are the applications of pre-cast ideas to a building constructed in industrialization.

Automation of Tying Reinforcement

The importance of tying and positioning of rebar raises after the fierce earthquake occurred on Sep. 21, 1999. The most traditionally denounced problem on site is the uncertainty of tying rebar. The ties with one-side 135° hook shall be adopted in according to the local Building Design Codes. And rebar tying is the most costing process and would result in the disagreement between construction and original design out of artificial negligence. Thus, the followings are the innovation and development aiming the positioning of reinforcement:

A. Column spirals are pre-manufactured in factory in unity

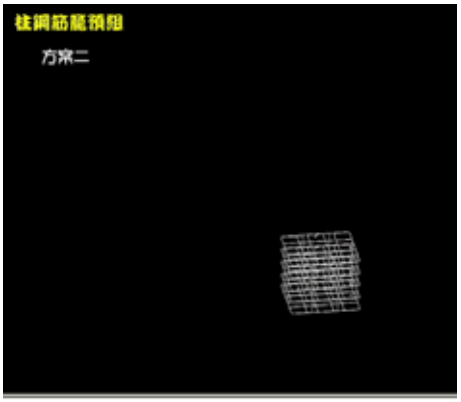
Traditionally, the earthquake resistant ties of columns are added after the confined ties are positioned to increase the bearing capacity at ultimate state. However, because of the difficulty in making 135° hooks on job site, the angles are often disagreed with the Building Regulations.

That is the reason why unified spirals are adopted in pre-casting. The so-called unified spiral is to curve the reinforcement to the desired shape by steel fabricators in factory, as shown in Fig. 1. The advantage of this method is that the spiral is bent continuously from a single rebar and the confinement is not less than the traditional column ties. The spirals are to be inserted after delivering to site. This would save the working schedule on job site and largely expedite the speed of construction.

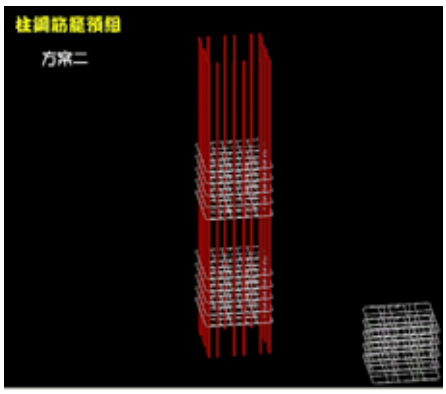
As for the assembly of rebar cage, it is able to use several short straight rebar and position them into one lot by stacking unified spiral for each 5 bars. And connect the lots with longitudinal reinforcements to make a semi-rebar cage. Then insert other lots into the semi-rebar cage as shown in Figure 2. Therefore, it is able to save the required time for penetrating all reinforcement through rebar cages one by one. The tying jobs for rebar cages are then expedited.

B. Pre-assembly of stirrups for beam elements

Figure 1 unified spiral



Step1: stacking unified spirals in lots



Step2: put longitudinal rebar into one lot then insert other lots to finish cage

Figure 2 Pre-assembly of Rebar Cage for Column

The method is to utilize welded wire fabrics and bend them, of which the spacing is decided by the original structural design, into semi-closed stirrup cages in factories in advance (Refer to Figure 3). After erecting and positioning the stirrup cages on site, the longitudinal reinforcement is then positioned and tied. The cap fabricated by the same way is covered to complete the assembly of the stirrup cages as shown in Figure 4. The advantage of this method lies in the precision of positioning and spacing of the stirrups. No layout jobs are required on site. It could save considerable time for tying rebar, and increase the safety of the structure.

C. Machine for rebar cage assembly

The process of assembly of rebar cages is quite complicated and wastes both time and labor costing. The accuracy of such task largely concerns with the safety of the pre-cast structure. It has become a fairly important item in pre-cast engineering that how to complete the rebar cages correctly and quickly. Those steps utilizing machine for rebar cage assembly are to (1) tie the column ties beforehand and (2) place them in order on a platform, as shown in Figure 5. (3) The longitudinal reinforcement is penetrated through the column ties by positioning rollers anchored at both sides and it is shown in Figure 6. (4) Then, move the ties onto the movable platform one by one. The only job to be done during the tying process is to rotate the

Figure 3 Stirrup Cage for Beams

Figure 4 Construction of the Cap of Stirrup Cages

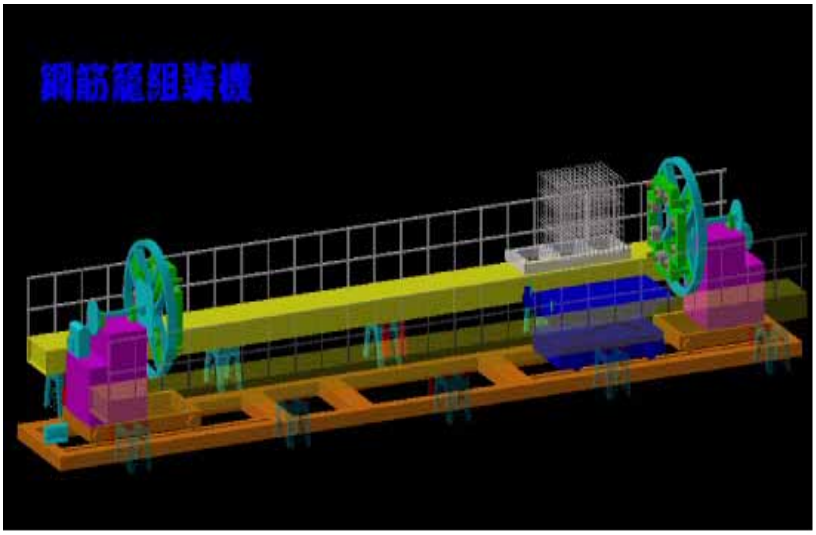


Figure 5 Machine for Rebar Cage Assembly step1: put all transverse ties on platform and rearrange them into right position by hanging upon two longitudinal rebar

positioning end plate at both sides. And we could tie bars easily and save 10%~33% of labor cost as shown in Table 2.

Pre-cast Construction Method for Concrete Structures

Pre-cast construction method, a method that combines design management, material science and manufacture technology, integrates architectural, structural, mechanical and electrical systems in addition to high technology concrete materials as well as the precise erection management. The structure elements of a building, such as columns, beams, slabs, walls and stairs, are produced in factory in advance and fast assembled by tower cranes or mobile cranes

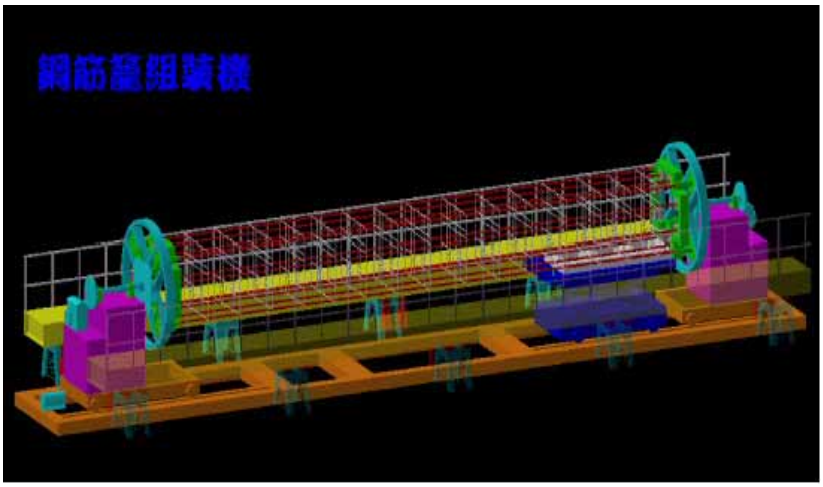


Figure 6 Machine for Rebar Cage Assembly step2: rotating wheels where longitudinal rebar are fixed temporarily makes tying rebar easier.

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items	steps	Mechine (Original)	Mechine (Modified I)	Mechine (Modified II)	Mechine (Modified III)	Tranditional way
	workers	Thai worker	Thai worker	Thai worker	Thai worker	Taiwan worker
I	adjust hooks	57'x2人=114'	53'x2人=106'	49'x2人=96'	46'x2人=92'	
	set hooks					15'x2人=30'
	erect hooks	10'x2人=20'	10'x2人=20'	7'x2人=14'	5'x2人=10'	
II	put rebar	14'x2人=28'	13'x2人=26'	8'x2人=16'	8'x2人=16'	8分x2人=16分
	fix rebar					1.5'x2人=3'
III	move hooks	4'x2人=8'	4'x2人=8'	4'x2人=8'	4'x2人=8'	3'x2人=6'
IV	tie hooks	26'x2人=52'	26'x2人=52'	26'x2人=52'	22'x2人=44'	20'x2人=40'
	put cross ties					44'x2人=88'
	tie cross ties					33'x2人=66'
time(min,sec)		224'	212'	186'	170'	263'
weight per sets(t)		0.79348	0.79348	0.79348	0.79348	0.825288
rate (hr/t)		4.71	4.45	3.91	3.57	5.31
percentage(%)		89%	84%	74%	67%	100%

Table 2 Time to assemble rebar cage by machine are less over 10% than that by traditional way

on site. Not only it is not influenced by the weather but also it could strictly control the quality.

Figure 7 illustrates one typical cycle of the pre-cast construction method for concrete structures. The advantages of pre-casting are the fast erection speed (4 to 7 days per floor), the production of elements are not influenced by the weather but produced at plant while foundation work are constructed in job site, and the easy quality control with simply manufacturing procedures.

The cost of materials of concrete structures is 30 to 50% lower than that of steel structures. This is the reason why reinforced concrete structures are widely adopted. However, the

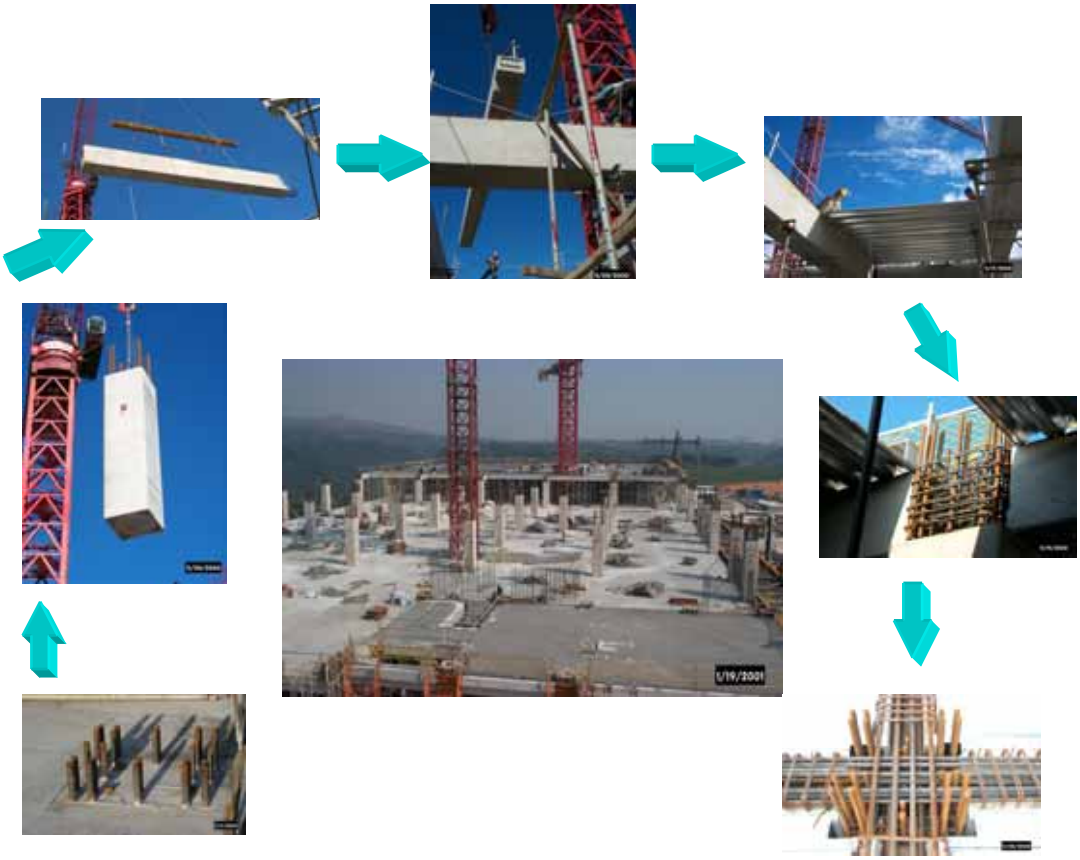

Figure 7 A typical construction cycle for a hypermarket building using Precast

disadvantage of concrete structures require more time in comparison with steel structures because of complicated jobs on site and it takes time for concrete to develop its design strength for further construction. Pre-casting preserves the advantage of lower material cost and adds the characteristics of steel structures that produce structural elements in factory and erect elements by automatic machine. There are merely a few assembly jobs on site. Due to pre-casting, the strength of elements has already been developed before erecting. So the speed of construction could be largely increased. The required construction period for pre-casting is even days shorter than the period needed for steel structures.
The quality of concrete could be easily controlled due to the production is done in factory. In addition, for easy site assembly (For construction cycle please refers to Figure 7) the shop drawings are to be drawn in unit of millimeter for both lengths and locations of rebar in pre-cast segments to ensure that the rebar will not collide. Compare to traditional concrete structures, the allocation of reinforcement is not well examined but the total reinforcement area is stated. Nonetheless, the reinforcement is often too crowded that it has to be cut up or offset. Pipelines of water and electricity are usually in disorder and the quality control is uneasy while cast concrete in place. In comparison with the two construction methods, the quality of pre-cast structures is largely increased. Quality and construction speed are actually one story. Imagine, if the dimensions of elements are not precise and the reinforcement collides, how could the construction be accelerated?

Not all buildings are appropriate for pre-casting. It depends on whether structural safety, cost, workability, access roads for transportation could meet the requirement or not. Architects and professional engineers often consider adopting a composite construction method which combines both pre-cast method and cast in-situ method to overcome the difficulties. That

means the modularized parts adopt pre-cast methods, others adopt traditional method.

APPLICATIONS OF COMPOSITE CONSTRUCTION METHODS

The purpose of industrialization is to achieve mass production to provide products with lower price and higher quality by means of machinery production. Owing to mass production for construction could not satisfy each of the consumer's needs, the industrialization in construction is far behind that in other industries. At this moment, we need to choose a "composite method" that meets individual requirements by selecting construction methods, management technology and new materials from all existing knowledge. From design point of view, it shall consider the following 3 items: 1. Construction method, 2. Management, and 3. Material. The 3 items are stated as listed below.

Construction Method

A. Precast waffle slabs

The traditional construction of slabs of wafer fabs is to cast primary columns in place and install scaffoldings in large area after the primary columns are completed. The formwork and rebar tying of grid girders are done on those scaffoldings and then the concrete is poured. After the concrete develops its strength, the shoring is removed. Resin coating is applied after the concrete is sufficiently dried to prevent micro granules spoiling the cleanness of the surface. The grid girders are then finished.

The difficulties in construction adopting traditional design are listed below.

1. Large area of scaffolding influences the working access routes.
2. The jobs done on scaffolding, such as setting up formwork, placing rebar and making recesses are difficultly done in the air. And the quality could not be controlled.
3. All difficult tasks are in the way of critical path. It seriously affects the operating schedule.
4. For longer construction period, it is easy to postpone the completion date by the weather and it conflicts with other jobs on site.

Because the difficulties in constructing for waffle slabs, the idea of semi-Precast is raised to overcome this perplexity. The so-called semi-Precast construction method is to use upper grid slabs, which forms as a whole with the dish-shaped precast grid slabs at lower part. There are concaves where small circular tubes could be inserted on the top face of the upper thin grid slabs (See figure 8). The central part of the slab contains several rectangular recesses. Polygonal blocks could be inserted in the recesses to integrate the dish-shaped grid slabs into unity. These semi-precast segments are grouted after delivering to site and anchoring on fixed primary columns.

The above-mentioned construction method is not affected by the weather and highly quality controlled as the pre-cast segments are produced in advance in factory. The only task on site is to erect the segments by mechanical equipments. Furthermore, the strength of the pre-cast bottom slab not only makes scaffolding system and formwork setting unnecessary but also removes the most difficult job from critical path. This makes it possible to precede mechanic and electric engineering on bottom floor slabs while constructing top floor slabs. Construction

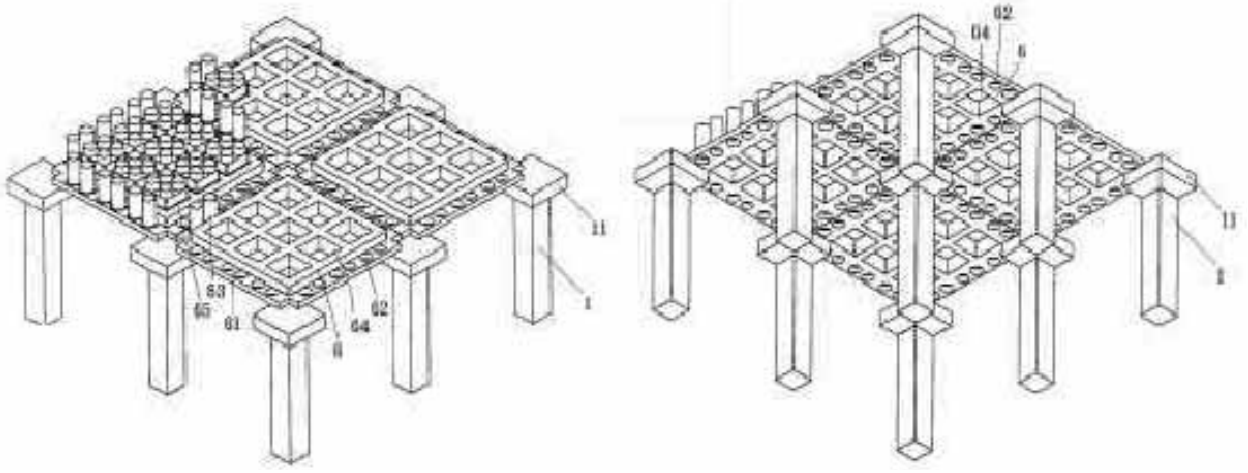

Figure 8 Semi-precast Waffle Slabs seating on precast columns with four-side bracket are divide into segments base on those grid lines

period is largely reduced.

The recesses in grid slabs divide the element into several small units. Each unit has merely space for longitudinal and transversal rebar cages and concreting. In this structural condition, the placement of both longitudinal and transversal rebar cages and false assembly become very difficult. This method allows pre-assembly of longitudinal and transversal rebar cages, respectively and fast connection of the rebar cages to achieve effective integration. The positioning devices are installed corresponding to the pre-cast elements. Firstly, we insert the transversal rebar and put the longitudinal rebar on auxiliary brackets temporary. Then, the longitudinal reinforcement is pushed into the recesses (Figure 9). This method is applicable to save considerable manpower, reduce the difficulty in construction and increase the efficiency.

B. RT girder at large spans

Truss systems are widely used in steel structures. Especially in structural systems with large spans, light trusses are needed. However, the application of truss concept on reinforcement concrete structures is rare. It seems that concrete structures with large spans could only be dealt by pre-stressing. The design of RT girder is evolved from truss system. The advantages of large span RT girder are not only reducing the self weight, but also the pipelines of air conditioning and electrics could be penetrated from the inner holes to increase the clearance as shown in Figure 10.

Management

A. Concurrent construction

Traditional construction manages with “series connection”. The so-called series connection indicates that the construction procedures have to be completed one by one. The length of the construction period depends on the construction speed of every single job and the catch up speed of the ladder and next procedures. Entering e-generation, the out-of-fashion method shall be changed thoroughly. Every procedure shall be completed “in parallel”, or overlapped. Take pre-cast buildings for example; the fixing up job is proceeding while the pre-cast elements are under construction. The progress differs between two stories. Thus, the

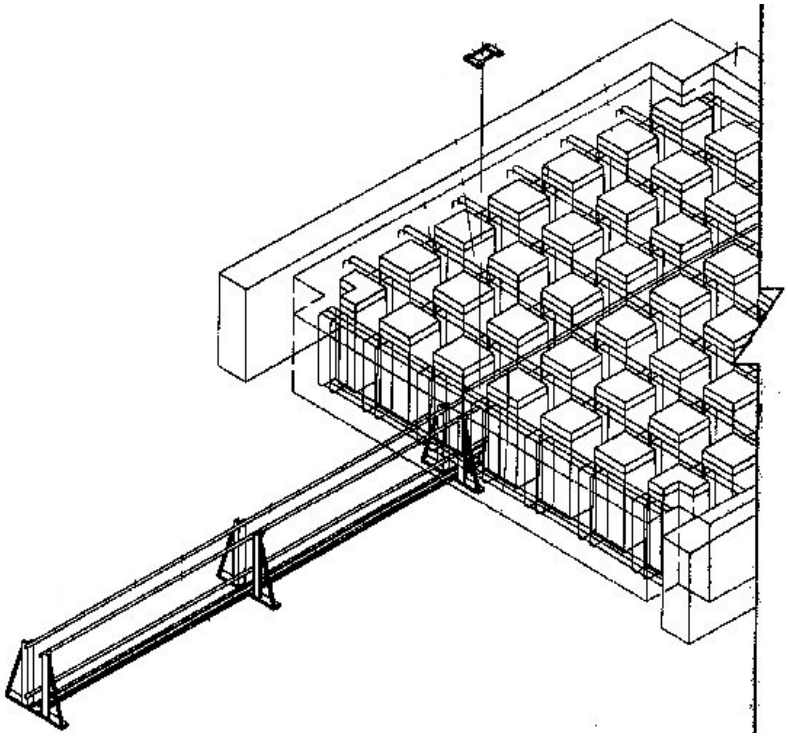

Figure 9 Rebar Cage of Pre-cast waffle slabs

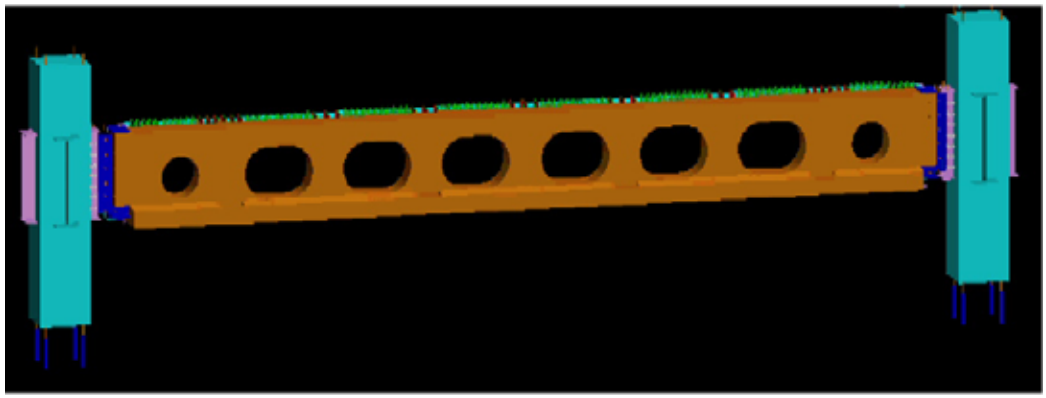

Figure 10 RT Girder at Large Spans

construction speed of pre-casting is fast than steel structure. The concurrent construction requires the progress of each construction task to avoid conflicts. And 3-dimensional computer software as well as the software for construction arrangement shall be used to examine the all the construction procedures by 4-dimensional models, which are considered with 3-dimensional space and time. The advantages of concurrent construction are then developed (See figure 11). In Taiwan, this type of computer aided analysis is widely applied on establishing databank center to ensure the whole data is operating in 99.9999% of time in each year. And the electrical equipments of data backup system could provide stable operation even under unexpected catastrophe.

B. Examination on the 3-dimensions

Rigorous preliminary plans and self-examination are necessary for synchronized construction

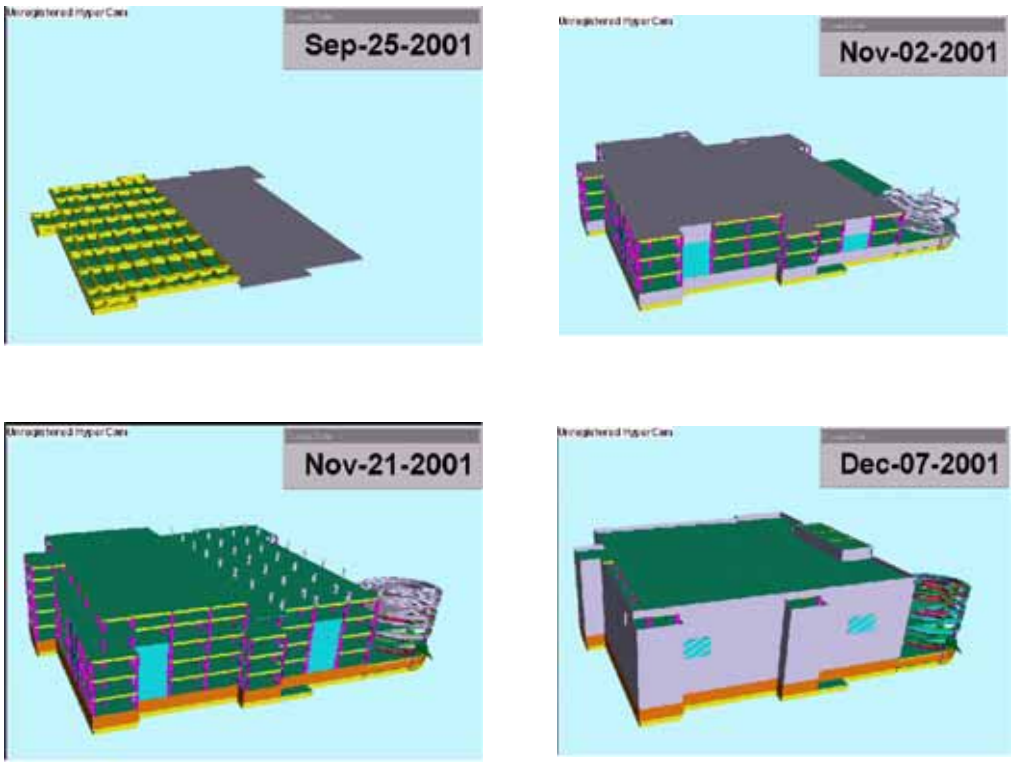

Figure 11 3-dimensional model of computer software

to work out at higher efficiency. Therefore, the examination on the 3-dimensions, architecture, structure, electricity and mechanic, are by contrast becoming quite important. This relies on the computer aided software to precede this task. (See figure 12)

Materials

A. Self-compacting concrete

Self-Compacting Concrete (SCC) is a special concrete material that is able to fill itself into space between reinforcement and corners by its excellent workability without any compacting or vibrating jobs. Normally, the pouring of normal concrete requires considerable vibration and compact. If the two procedures are not sufficiently completed, honeycombs will exist inside the concrete structures. But, over compacting would cause the submergence of aggregate and floating. The most important meaning of using SCC is to ensure the solidity of concrete structures and bonding strength between concrete and rebar. With qualified SCC, it could easily fill the space automatically without compact and vibration. And it is not necessary to consider the construction flaws and the reduction in structural bearing capacity by using SCC. Meanwhile, the SCC could be examined immediately to identify whether it is qualified or not. Thus, we could handle the unqualified material promptly and avoid the problems after pouring (Figure 13).

B. Test on elements using concrete strength of 10,000psi

It is a tendency to adopt high performance concrete. However, the design code for concrete considers the difficulty in quality control on site and regulates the compressive strength of concrete shall not exceed 420kg/cm2. In the case of pre-casting, the quality of concrete elements is assured because the production is done in factory. Thus, we precede the test on elements using high strength concrete to confirm that the bearing capacity could meet the

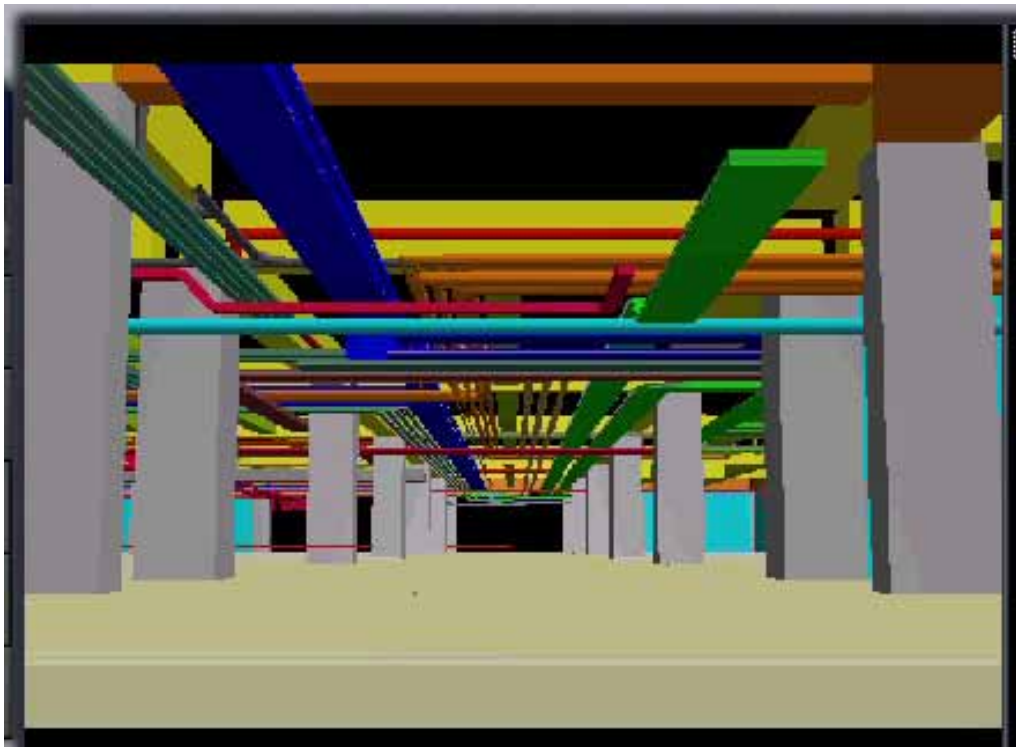

Figure 12 3-dimensional examination on architecture, structure, and mechanic and electricity

Figure 13 Self-compacting concrete

design requirements.

C. Self-leveling mortar

The development of self-leveling mortar indicates a big progress of floor construction in

industrialization. In the traditional operating procedures, it requires a large amount of labor to complete the leveling and finishing work. If large area of slabs or floors is done by applying self-leveling mortar, it is able to complete leveling and finishing at once and the only job to be done is removing the voids in the grout using trowels. It is labor saving. Besides, self-leveling concrete has high early strength, which is 3500 psi at the age of 24 hours after pouring. The construction progress could easily be controlled. The characteristics of high strength and high wear-resisting ability make it applicable in heavy loading floors, such as factory buildings, outdoor parking lots, shopping malls and gas stations.

CONCLUSION

There is still much space for the development of industrialization in building construction. And pre-cast segment construction method is one of the paragons of industrialized construction. Because of the production is done in factory, it is fairly easy to enhance the quality through automatic manufacture processes from industrialization. Nevertheless, the industrialization of building construction requires the idea of composite methods that combines various construction methods, management technology and development of new materials so as to acquire lower cost and higher competitiveness as a goal. In the process of industrialization and composition, computer technology plays a very important role. It not only shortens the research period of automation but also accomplishes the optimized allocation of architecture, structure, mechanic and electrical devices. The above-mentioned processes are still improving with the aid of computer technology to provide higher quality and diversification for building requirements.

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