Study on BIM Family Self-create for Steel Reinforcing Bar Detail Construction Design and Information Extraction

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Abstract –

In this study, the frequently encountered issues related to reinforced concrete nodes (beam and girder protection layers, beam column protection layers, and binding wire collision, etc.) were sorted out and analyzed. Building Information Modeling (BIM) was employed to solve the problems resulted from the complex node issues. Moreover, new steel reinforcing bar family (*.rfa) were constructed using the shared parameters to edit formula, to assign parameters to steel reinforcing bar processing and construction, to export detail list, to facilitate steel reinforcing bar data-processing and construction in the later stage. Lastly, a steel reinforcing bar construction process was constructed based on the BIM application presented by this study, serving as reference for the steel reinforcing bar works.

Keywords –

Complex reinforced nodes, Building information modeling (BIM), Steel reinforcing bar parameterization, Construction process

1 Introduction

Concrete frame is widely used as an architectural structure. Steel reinforcing bars constitute 15%-20% of construction costs, the larger the steel content, the higher the steel reinforcing bar costs **[1]**. Steel reinforcing bar works entail a high level of professional know-how throughout a fussy, massive and complicated construction process. Thus, the importance of steel reinforcing bars, a sub-project of construction plan, is overlooked most of the time and lots of steel reinforcing bars are wasted inadvertently. To use steel reinforcing bars economically, a rational design and construction process are essential. Therefore, effective measures are needed to prevent steel reinforcing bars from being wasted, and at the same time to ensure economic benefits and social benefits. Surprisingly, hardly any constructor is aware of the issues related to the steel reinforcing bar arrangement and structure as well as the complex and intensive nodes. As a result, node quality worsened, affecting the architectural structure quality severely. Information technology is therefore needed to improve construction quality. Building Information Modeling (BIM) has tremendous potentials to be explored in the days to come. BIM is noted for its superior ability to design and arrange steel reinforcing bars, to solve the complex issues related to the reinforced concrete nodes, to store steel reinforcing bar information, and to find the solutions for the effective use of steel reinforcing bars.

2 Frequently encountered issues related to reinforced concrete nodes and solutions

Concrete frames are made up of beams, girders and nodes. Steel reinforcing bars are arranged complicatedly and intensively in the beams. Longitudinal reinforced bars are interlocked, overlapping each other in the upper areas of beams. In the conventional structural design, the diameters of steel reinforcing bars are not exhibited. The conventional two-dimensional construction drawings do not display the arrangement of steel reinforcing bars which are visible in a three-dimensional space only. As a result, many issues occur in the construction process, for example steel reinforcing bars are bent arbitrarily and there is assurance for the thickness of protection layers. Up until today, Revit is one of the most popular software employed by the architectural BIM system, and with its powerful parameterization ability, Revit has the largest market share. In this study, the frequently encountered issues related to the complex nodes of reinforced concrete were analyzed in an attempt to find the technical measures to solve the complex node issues, and at the same time Revit was employed to simulate how the nodes were treated effectively.

2.1 Issues related to beam and girders' protection layers

The diameters of steel reinforcing bars are not exhibited in the conventional two-dimensional drawings. In the construction site (same as a 3D drawing), however, a number of reinforced concrete nodes are made up of steel reinforcing bars overlapping each other. Many overlapping nodes are seen in the beam-to-girder nodes, each node comprising three layers – floor reinforced bars in the upper layer, girder's longitudinal bars in the middle layer, and beam's longitudinal bars in the bottom layer – all steel reinforcing bars overlapping with each other. With so many steel reinforcing bars overlapping each other, the thickness of protection layers on the surface steel reinforcing bars has decreased to almost zero and the girder steel reinforcing bars are not adequately thick, either (Figure 1), which is inconformity to the requirements stated in the "Code for design of concrete structure" **[2]** and "Code for acceptance of constructional quality of concrete structure" **[3]** regarding the thickness of protection layers (For beam and its structural components: +10mm, -7mm; for girder and its structural components: +8mm, -5mm).

In reality, it is a common practice to arbitrarily strike, press or bend the steel reinforcing bars of beams and girders after the concealment works of steel reinforcing bars are accepted. This practice does not really serve the purpose and is unable to warrant the thickness of the protection layers and is likely to decrease the load-carrying capacity of the twisted steel reinforcing bars, affecting the structural safety.

Proposed method: Based on the requirements stated in "Drawing Rules and Standard Detailing Drawings of Ichnographic Representing Methods for Construction Drawings of R.C. Structures (Cast-in-situ R.C. Frames, Shear Walls, Beams, Slabs)" **[4]** and in conformity to the common practice of the construction site, a pre-bending smaller than 1:12 ($\geq 170.54^{\circ}$) was proposed for the longitudinal steel reinforcing bars of the beams involved in the node while stirrups were shrunk down (Figure 2) to ensure the stability of reinforced concrete framework. In other words, beam stirrup's height decreased by the length of one steel reinforcing bar's diameter, allowing girder longitudinal steel reinforcing bar with same diameter to fit into the node. It was therefore proposed that BIM technology was employed to solve similar issues at the time that reinforced concrete frameworks were constructed. Lastly, diagrammatic sketch of Revit model was presented as shown by Figure 3.

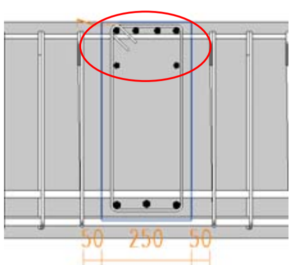


Figure 1. Inadequate thickness of beam and girder protection layer

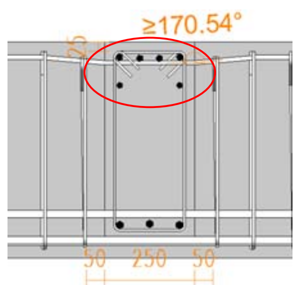


Figure 2. A proposed method for beam and girder construction

Figure 3. A diagrammatic sketch of beam and girder construction by Revit

2.2 Issues related to bam column node's protection layers

Beam column's steel reinforcing bars have same problems as the beam and girder node's steel reinforcing bars. Steel reinforcing bars' collision causes the beam steel reinforcing bar's protection layer to become thinner. When the longitudinal steel reinforcing bars in the upper area of girder are lifted, the beam steel reinforcing bar's protection layer becomes thinner and the structural durability reduces. As shown by Figure 4, with the reduced durability, beam column node is no longer in conformity to the safety requirement. To ensure the steel reinforcing bar's protection layer thickness, the concrete cement in the areas nearby the node has to be lifted. As a result, the building interior installation and repair works becomes extremely difficult. To solve this problem, some layers have to be removed. Apparently, both methods do not serve the purpose rationally and are unable to elevate concrete cement structure as required by the safety specifications.

Proposed method: If protection layer is not thick enough or has zero protection, steel reinforcing bars are exposed to the air and are likely to be rusted, affecting the concrete cement structure's durability. It is proposed that the nodes are treated in the same way as the beam and girder nodes are treated. As shown by Figure 5, a pre-bending smaller than 1:12 was proposed for the longitudinal steel reinforcing bars of the beams involved in the node. When beam's steel reinforcing bars are twisted, the beam's effective height decreases. To maintain the beam's load-carrying capacity unchanged, edge reinforced bars were paved along the beam. The length of edge reinforced bars was equal to 12 times of the diameter of the steel reinforcing bars on both sides of girder plus the anchorage distance of the steel reinforcing bar [5]. The Revit effect for the nodes is shown by Figure 6.

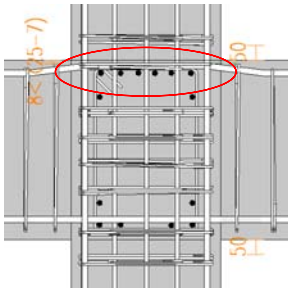


Figure 4. Inadequate thickness of beam column protection layer

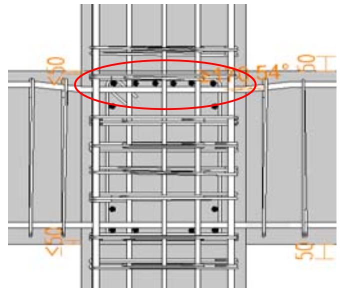


Figure 5. A proposed method for beam column construction

Figure 6. A diagrammatic sketch of beam column construction by Revit

2.3 Issues related to beam column binding wire collision

In many cases, concrete frame's beam and its column have same width, or one side of concrete frame's beam is even with one side of its column. If that's the case, the concrete frame's outermost longitudinal load-carrying steel reinforcing bars collide with the concrete frame column's outer longitudinal steel reinforcing bars. As shown by Figure 7 and Figure 10, side column collides with corner column noticeably. In the steel reinforcing bar construction, it is a common practice that the column's longitudinal steel reinforcing bars are either bent arbitrarily or interspersed without bending. As a result, there are more stirrups and less space in the nodes, and with too many stirrups, node becomes disorganized, affecting the steel reinforcing bar construction efficiency and quality.

Proposed method: in the node, beam's longitudinal steel reinforcing bars collide with each other and the corner column's longitudinal steel reinforcing bars are unable to move. A pre-bending smaller than 1:12 was proposed for the beam's longitudinal steel reinforcing bars, allowing the outermost longitudinal load-carrying steel reinforcing bars to pass through the space inside the longitudinal steel reinforcing bars which are provided outside the concrete frame and at the same time shrink down the stirrups as shown by Figure 8 and Figure 11. By doing so, the protection layer is likely to grow larger than 50mm and the concrete cement's protection layer breaks apart, affecting the longitudinal load-carrying capacity and structural durability. It was therefore proposed to install crack-resistant steel meshes to prevent steel reinforcing bars from breaking apart. The Revit processing chart of side column and corner column is shown by Figure 9 and Figure 12.

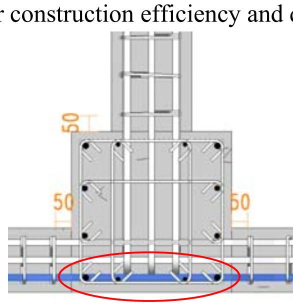


Figure 7. Side column's longitudinal steel reinforcing bar collision

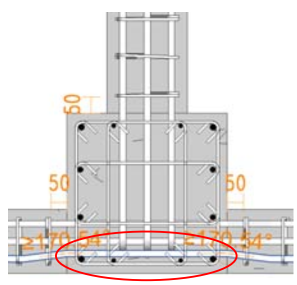


Figure 8. A proposed method for side column's steel reinforcing bar construction

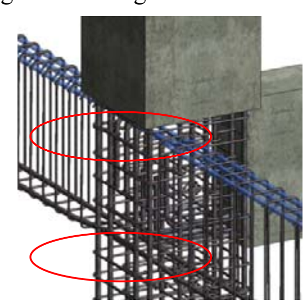


Figure 9. A diagrammatic sketch of side column construction by Revit

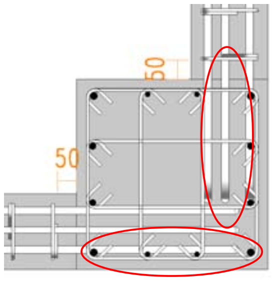


Figure 10. Corner column's longitudinal steel reinforcing bar collision

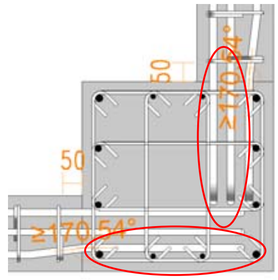


Figure 11. Corner column's longitudinal steel reinforcing bar collision

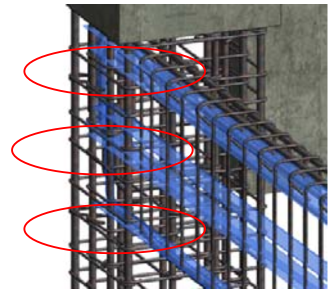


Figure 12. Corner column's longitudinal steel reinforcing bar collision

3 Steel reinforcing bar parameterization

Information is the most critical element required by BIM technology, and with the needed information, BIM is a valuable tool for three-dimensional modeling that allows users to store, transmit and run the data throughout the construction process, and thus make the best use of BIM technology. Revit information model requires all kinds of information and elements related to engineering design. All information and elements are systematically integrated into an interactive information organism. All components are parameterized for easy retrieval and modification. Geometric drawings are dynamically linked with attribute information. In Revit, pixels are grouped, depending on how the parameters (attributes) are shared and used, and are integrated into graphics. Family (*.rfa) parameters are divided into three categories, namely, family parameters, shared parameters, and special parameters. This study focused on how to create steel reinforcing bar families, how to establish settings, and how to store steel reinforcing bar's processing and construction information using Rivet in an attempt to solve the complex nodes stated in Section 2.

3.1 Setting parameters for steel reinforcing bar's processing

Revit's built-in steel reinforcing bar families have several shortcomings: (1) Only one steel reinforcing bar shape is available, unable to handle the deformable steel reinforcing bars, for example the pre-bending smaller than 1:12 stated in Chapter 2. (2) Revit software's built-in information is intended for modeling only, unable to meet the specifications in Taiwan regarding steel reinforcing bar data and processing. (3) Steel reinforcing bar families are intended for users. Yet, parameter setting permission is not open to users. Without permission, users are unable to set parameters as long as they like.

Based on the discussions stated above, shared parameters were chosen to set steel reinforcing bars' parameters. In this study, the corner columns' bending steel reinforcing bars stated in Section 2.3 were discussed. New steel reinforcing bar families were created, and at the same time drive parameters (A-D) were defined (Figure 13). However, the parameters were simply for line generation, without consideration to steel reinforcing bar's diameters and bend diameters. Therefore, the parameters were not ready to be applied to steel reinforcing bar processing.

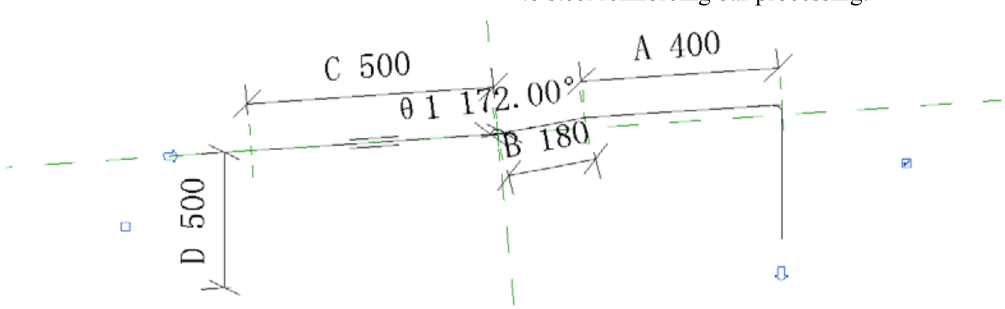


Figure 13. The shape of steel reinforcing bars created by this study

Steel reinforcing bar's processing parameters were established (A+) based on the steel reinforcing bar's diameter and processing requirement. Next, the formula was edited in accordance with the setting mechanism and geometric relationship between both parameters (A+ = A – sin ((180° - 172°) /2) x 3 x steel reinforcing bar's diameter – 2.5 x steel reinforcing bar's diameter). The final processing parameters setting, as shown by Figure 14 and Figure 15, exported a detail list (Figure 16) which included data such as steel reinforcing bar's diameter C+, bend diameter Ö+ and angle è+. With the detail list, the parameters were ready to be applied to digital control and processing.

θ2+(默认)	90.00°	=90°
θ1+(默认)	172.00°	=θ1
θ1(默认)	172.00°	=
Φ+(默认)	40.0	=if(钢筋直径 > 25 mm, 6 * 钢筋直径, 4 * 钢筋直径)
D+(默认)	120.0	=12 * 钢筋直径
D(默认)	145.0	=
C+(默认)	497.9	=C - sin((180° - 172°) / 2) * 3 * 钢筋直径
C(默认)	500.0	=
B+(默认)	175.8	=B - 2 * sin((180° - 172°) / 2) * 3 * 钢筋直径
B(默认)	180.0	=
A+(默认)	372.9	=A - sin((180° - 172°) / 2) * 3 * 钢筋直径 - 2.5 * 钢筋直径
A(默认)	400.0	=

Figure 14. Steel reinforcing bar's processing parameter setting

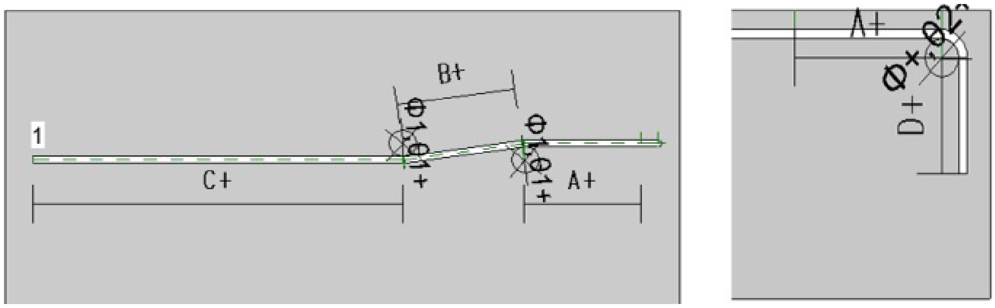


Figure 15. Steel reinforcing bar's processing parameters in motion

钢筋加工明细表

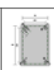
钢筋直径	钢筋长度	合计	形状图像	A/	B/	C/	A+/	B+/	C+/	D/	D+	Φ+	θ1+/	θ2+/	θ+/
6 mm															
6 mm	1520 mm	89		200 mm	500 mm		160 mm	460 mm	80 mm			24	90.00°	135.00°	
8 mm															
8 mm	1320 mm	20		170 mm	450 mm		120 mm	400 mm	80 mm			32	90.00°	135.00°	
8 mm	1380 mm	40		200 mm	450 mm		150 mm	400 mm	80 mm			32	90.00°	135.00°	

Figure 16. Steel reinforcing bar's processing detail list

3.2 Steel reinforcing bar's construction positioning setting

Construction management is very important for steel reinforcing bar works. Steel reinforcing bar system's built-in partitioned attribute columns are helpful tools for project management. In the early stage, modeling staffs assign steel reinforcing bars and accessories to a component. Then, they discuss matters related to construction positioning and progress in the later stage. To cope with most people's habits and the steel reinforcing bar's mutual anchorage, this study chose a building's one facade as front facade (customized by this study) and longitudinal steel reinforcing bars were paved from left → right, from front → rear, from bottom → top. The component first seen in the ending area was treated as the linked component of the longitudinal steel reinforcing bar. Accessories such as stirrups and pull bars were linked with the components in the same areas. As shown by Figure 17, filter programs were created in accordance with the definitions and rules. Black steel reinforcing bars belonged to girder KLx-Aa(4)-3 while red steel reinforcing bars belonged to girder KLx-Aa(4)-4. Thus, construction detail list and Revit three-dimensional model were exported to guide the steel reinforcing bar construction (Figure 18).

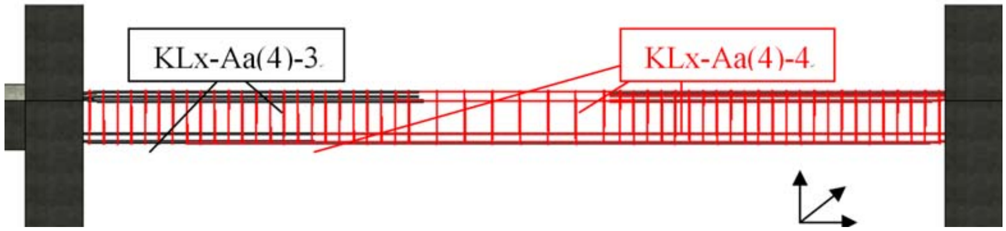
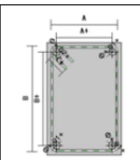
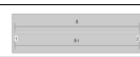
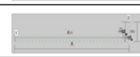


Figure 17. Steel reinforcing bar components' linking rules

钢筋施工明细表

分区	钢筋直径	钢筋长度	形状图像	合计	A/	B/	C/	D/
KLx-Aa(4)-4								
KLx-Aa(4)-4	8 mm	1560 mm		55	150 mm	550 mm		
KLx-Aa(4)-4	12 mm	2050 mm		2	2050 mm			
KLx-Aa(4)-4	16 mm	3530 mm		1	3320 mm	240 mm		
KLx-Aa(4)-4	18 mm	7160 mm		1	6930 mm	270 mm		
KLx-Aa(4)-4	18 mm	7160 mm		1	370 mm	140 mm	6420 mm	260 mm
KLx-Aa(4)-4	20 mm	3580 mm		1	3320 mm	300 mm		
KLx-Aa(4)-4	20 mm	3580 mm		1	410 mm	150 mm	2770 mm	290 mm

总计: 62

Figure 18. Steel reinforcing bar construction detail list

4 BIM-based discussion of steel reinforcing bar construction process

4.1 BIM steel reinforcing bar detailing model

The issues related to the complex nodes were reviewed and feasibility recommendations were proposed accordingly. Next, conventional two-dimensional drawings were converted into BIM steel reinforcing bar detailed models using BIM software (e.g. Revit). Construction simulation and collision checkup were carried out in the process. The model was so detailed that it could serve the construction needs sufficiently.

4.2 Self-constructed steel reinforcing bar families

Complex nodes were reviewed in compliance with domestic specifications. Steel reinforcing bar families were constructed accordingly. Then, relevant information was obtained and stored, and at the same time formula was employed to estimate the data obtained from steel reinforcing bar families. The estimation results were retrieved and used in the later stages.

4.3 Exporting steel reinforcing bar detail list

Steel reinforcing bar information was retrieved and adjusted using Revit detail list, and at the same time steel reinforcing bar processing and construction detail list was created. The parameters contained in the steel reinforcing bar detail list were sufficient to satisfy the digitalized processing needs.

4.4 Steel reinforcing bar construction and management

Steel reinforcing bar construction detail list and Revit model were employed to administer steel reinforcing bar installation & positioning and progress control.

The overall discussion of steel reinforcing bar construction process as shown by Figure 19

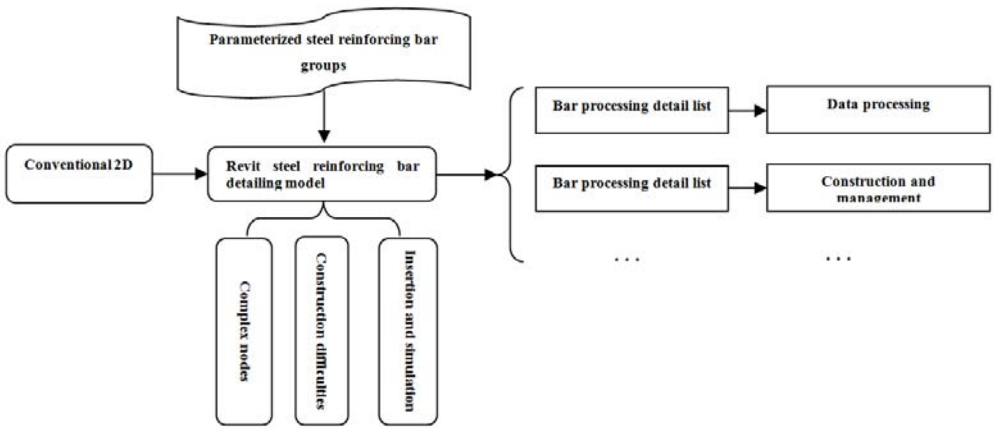


Figure 19. BIM-based discussion of steel reinforcing bar construction process

5 Conclusions

In this study, BIM technology was applied to steel reinforcing bar works. BIM-based steel reinforcing bar construction process was proposed. Moreover, BIM technology was employed to simulate the frequently encountered issues related to the complex nodes, and with the simulation results, parameterized steel reinforcing bar families were constructed for experimental processing and construction. The experimental results were sufficient to solve the real construction issues and to enrich the content of BIM technology.

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