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Investigation of Field Construction and Economic Efficiency for Steel Plate-Concrete Structures with Application of Parking Building

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Abstract

The SC structure can have relatively liberal sectional surfaces, and allows modularization for pre-forming in factories and structural stability. It can be used for the shear walls in the core of general buildings or the structural members for parking buildings. In the future, it could be applied to moving large bus terminals, and widely used for general industrial structures as it can expedite the process compared to other methods. This study examined the applicability of SC structures to the retaining walls of a parking building and reviewed its economic value by comparing its construction term, quality control benefits, and cost compared to RC structures. It was found that SC structures are about 1.6-1.7 times more expensive than RC structures in terms of the cost of fabrication and installation. However, the construction term can be reduced by 27% to save indirect costs for constructors, as well as the cost of removing molds and material loss required when installing RC structures.

Keywords : steel plate-concrete structure, field construction, economical efficiency

1. Introduction

1.1 Research objective

With the improvement of quality of life and the advancement of architectural technology as well as diverse architectural demands in the rapidly changing and diversifying modern society, construction projects are becoming larger and higher[1]. These changes demand members with structural strength or convenience for safe composition in a small space. The structural members required for these conditions are high-strength concrete or high-strength steel materials. Studies have been actively conducted on the development of high-performance concrete or high-strength steel materials and synthetic members through substantial construction industry-academic collaboration[2,3].

In addition, to meet these requirements, structural advantages from members have been combined to make a synthetic structure that can have lighter weight and smaller section while having higher rigidity and bearing more load compared with the conventional members[4,5]. The steel framed reinforced concrete(hereinafter SRC) column has been developed in a synthetic structure, and is widely used, from which the steel plate-concrete(SC) technology was developed that is used for nuclear facility structures. As shown in Figure 1, the SC structure an integral synthetic structure, is made by placing concrete between sandwich steel sheets to complement the weak-

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nesses of materials, e.g. brittle failure of concrete and buckling of steel plate. The SC structure is a synthetic structure that can have a freer sectional shape in terms of constructability and space composition compared with conventional CFT and SR structures. In addition, as with the SC structure it is possible to form a thinner long side structural wall compared with reinforced concrete(hereinafter RC) structures, SC structures have been actively studied in Japan and the United Kingdom, and the research findings are now being applied to actual building construction[6,7].

In addition, the SC structure allows easy quality control since it can be manufactured in a factory. However, to apply the SC structure to a site, various elements are needed including transport and lifting plans, material carrying-in plan, and the assembly order to establish a thorough scheme of execution. This complex process is disadvantageous, and scant research has been done on the subject.

In addition, the SC structure has been limitedly employed for the structures of nuclear facilities (Shin-kori #3,4), but is expected to be widely applied to structures with relatively fewer numbers of opening, to fit the diverse functions of modern structures, but thus far the constructability and economic feasibility of the SC structure needs to be studied. Therefore, this study aims to apply the SC structure to the walls of an RC-structured parking space, and to verify the applicability of the SC structure by performing a forecast and comparison of construction duration between RC and SC structures and by conducting a comparative analysis of economic feasibility between them to verify the applicability of the SC structure in the field.

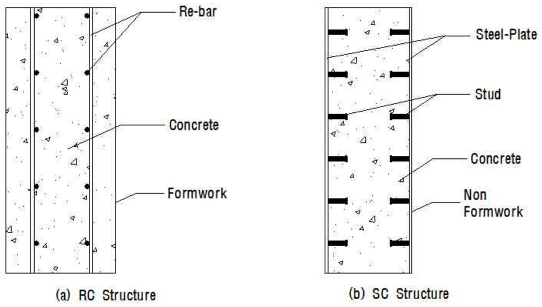

Figure 1. RC structure and SC structure

1.2 Research method and scope

In this study, the SC structure was applied to the RC-structured parking building to examine the construction duration and the constructability of the SC structure. SC structure technique is applied to the parking building because cracks on the RC structure and the moisture flowing in the cracks cause steel corrosion and ultimately have a great impact on the life span and safety of the building. When the SC structure is applied, these problems can be addressed, and the thickness of the retaining wall and the construction duration can be reduced compared with when using the RC structure. Therefore, the scope of this study is limited to the application of the SC to the walls of a RC-structured parking building.

1.3 Analysis of foreign cases of synthetic structural walls

As shown in Figure 2, the overseas cases where the composite structure of double-layered steel plate, which is similar to an actual SC structure, was adapted have been buildings built in England in 2003, referred to as Bi-Steel corefast[6]. This is the structural system that can greatly reduce construction duration, and was applied to the Birmingham 1 Tower, an 18-story OCN building in England, which can include 640 people, and it was usually employed in the core. As Table 1, the core was installed for 4 stories at a time and the surrounding junction and convenience facilities were finished in 5 days, and the entire construction duration was 120 days for an 18-story building when the conventional RC technique was employed, while it was 20 days for Bi-Steel[6,8].

Figure 2. Birmingham 1 tower (Bi-steel)

Table 1. Construction cases of Bi-steel

Field Construction case	Bi-Steel Construction	RC	Duration Reducing
Birmingham 1 Tower (Core)	20days (4 floor /5days)	120days	100days (84%)
London Political Science Building (core)	14days	120days	106days (88%)

2. Design of a parking building employing SC structure

2.1 Size of parking building

As indicated in Table 2, the building, analyzed by applying the RC structure in the underground part, is a composite hospital building located in Gangnam, Seoul. Its SC-structured lower part has operating rooms and medical equipment, and its ground part is steel-framed. The SC structure was applied to the structural part of the RC-structured underground parking induction ramp walls, and the economic feasibility and the construction duration and the lifting plan were compared and the applicability of the SC structure is scrutinized.

Table 2. Summary of construction

Contents	
Site	○○ hospital, Gangnam-gu, Seoul
Construction Time	2005. 7. ~ 2008. 10.
Total Floor Area	108,659㎡
Ramp Length of Parking Garage	59.44m
Retaining wall Thickness of Ramp	300~600mm
Width of Ramp	Inside wall 8.5m, Outside wall 16m
Parking	570 Cars

The parking building studied in this research is RC-structured, which means that it has no columns and that slab and beams are directly connected with the retaining wall. Figure 3 shows the structure whose ramp length is 60m in the long side and 30m in the short side, and the height is 4.5m, and the retaining wall is 300-600mm. Based on the dimensions, the reduction in construction duration and economic feasibility of the SC structure were compared.

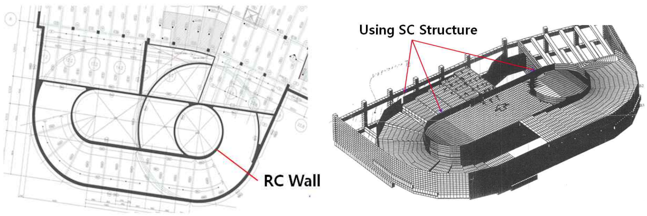

Figure 3. Application area of SC structure at parking garage

2.2 Discussion of the structure to determine applicability of the SC structure and the design

To employ the SC structure in the conventional RC-structured parking ramp, the ratio of reinforcement and structural requirements of the RC-structured parking ramp were determined. It was found that the SC structure should be made by estimating the critical stress and the nominal compressive strength in consideration of the interval between studs and the thickness of the steel plate when it is converted into the SC structure.

First of all, the maximum load of the RC structure should be reviewed, and then the SC structure designed. The maximum load of the steel framed concrete retaining wall (P_0) on which the central axial load is placed was calculated using Eq.(1) in reference to the construction design criteria(KBC2009)[9]. Here, the sectional size of the structure was set at 1000x300mm, and the size of the main bar was set as D19.

$$P_0 = 0.85 f_c' (A_g - A_{st}) + f_y A_{st} \quad \text{-------------} \quad (1)$$

Here f_c' : nominal compressive strength of concrete(MPa)
f_y : yield strength of rebar(MPa)
A_g : shear area of the retaining wall(㎟)
A_{st} : sectional area of the main bar(㎟)

if calculated with these factors,

$$A_{st} = 283.5 \times 14EA = 3{,}969 mm^2$$
$$A_g = 1{,}000 \times 300 = 300{,}000 mm^2$$

therefore, the maximum load(P_0) is,

$$P_0 = 0.85 \times 35 \times (300{,}000 - 3{,}969) + 400 \times 3{,}969 = 10{,}394{,}522 N$$

When the RC-structured parking ramp retaining wall is changed into the SC structure, the thickness of the SC structure that could bear the maximum load and have identical performance was calculated. Here, the thickness of steel plate(SS400) for the SC structure is assumed as PL-6mm. The interval between studs was examined as 250mm for Plan(1) and as 200mm for Plan(2), to select an effective interval ratio to the price reducing factors that satisfy the structural requirements and to make an economical design.

In general, as the design method of the SC structure, the design equation set out in Korea Electric Power Industry, KEPIC-SNG, confirmed in 2010, was utilized as shown in Eq.(2).

$$P_0 = 2A_p F_{cr} + 0.85 A_c f_{ck} \quad \text{---------------} \quad (2)$$

Here, f_{ck} : nominal compressive strength of concrete(MPa)
F_{cr} : buckling strength of steel plate(MPa)
A_p : sectional area of steel plate(㎟)
A_c : sectional area of concrete(㎟)

In addition, since the buckling of steel plate is an important factor to the SC structure, the buckling strength was set in accordance with the interval ratio of studs(B/t)[11].

$$\frac{B}{t} \le \frac{600}{\sqrt{F_y}} \quad \text{---------------------} \quad (3)$$

Here, when the yield strength of the steel plate(F_y) was set at 235MPa, Eq.(3) was calculated to be 39.13, the boundary between elastic and non-elastic buckling. Through this, the stud interval ratio was calculated to be 41.6($B/t = 250/6 = 41.6$) when using Eq.(1), and in this case the buckling of the steel plate is elastic. Therefore, the buckling strength(F_{cr}) was calculated to be 198.2MPa when using Eq.(4).

$$F_{cr} = E_s \frac{\pi^2}{12K^2(B/t)^2} \quad \text{----------------} \quad (4)$$

Here K : buckling length coefficient of the steel surface plate radially supported by studs(=0.7)
B : vertical interval between studs(㎜)
t : thickness of steel plate(㎜)
E_s : elastic coefficient of steel plate(MPa)

If the maximum load of the SC structure was calculated at 250×250㎜ of the stud interval for Plan(1),

$$P_0 = 2 \times (1000 \times 6) \times 198.2 + 0.85 \times (1000 \times x) \times 35$$

Here, x was the thickness of concrete, which could be calculated using a linear equation when P_o was hypothesized at P_0.

If $10{,}394{,}522 = 2 \times (1000 \times 6) \times 198.2 + 0.85 \times (1000 \times x) \times 35$ was calculated, the thickness of the SC wall was 282mm by summing 12mm and 270mm, which has the sectional area of 1,000×282 in the SC structure, equivalent to the structural performance of the sectional area of 1,000×300 in the RC structure.

Similarly, Plan(2) was calculated using the equations above. However, the stud interval ratio was 33.13, which is included in the non-elastic buckling area, and the buckling strength of the steel plate (F_{cr}) was calculated by applying 235MPa for yield strength(F_y), which is a difference. From the calculation, the thickness of concrete at the stud interval of 200 for Plan(2) was 219mm, and when 219mm was summed with 12mm thickness of steel plate, it resulted in 231mm, which appeared to have structural performance equivalent to that at 300mm thickness of concrete. Put simply, when the RC structure is changed with the SC structure to have the maximum load and the load stress equivalent to those of the RC structure, the thickness of the retaining wall decreases according to the stud interval ratio. There was an 18mm(6%) decrease at the stud interval of 250, and a 69mm(23%) decrease at the stud interval of 200.

3. Analysis of economic feasibility and constructability

3.1 Discussion of economic feasibility according to the stud interval in the SC structure

As described above, when the RC structure was replaced with the SC structure to have the maximum load and the load stress equivalent to those of the RC structure, it was found to be effective in decreasing the thickness of the wall. Tables 3 and 4 provide the comparison of the construction cost, in terms of concrete material cost and reduction in construction cost. Through the analysis, it was found that the reduction in cost resulting from stud interval ratio is greater than any other material cost or construction cost. More specifically, the SC structure with stud interval at 200 increased by approximately KRW16,000 per 1㎡ compared with the SC structure with stud interval at 250. In terms of the economic aspect, it is more economical to choose the stud interval at 250.

Table 3. The cost of construction(Stud @250)

Contract	Cost Contents	Unit	Price (won)	Cost of Construction			Reduction cost (won)
				Quantity	Price (won)	Sum (won)	
Concrete	Material	m³	57,653	0.018	1,037	1,181	▼1,181
	Construction		8,000	m³	144		
Stud	Material	EA	369	16	5,904	29,904	
	Construction		1,500	EA	24,000		

Table 4. The cost of construction(Stud @200)

Contract	Cost Contents	Unit	Price (won)	Cost of Construction			Reduction cost (won)
				Quantity	Price (won)	Sum (won)	
Concrete	Material	m³	57,653	0.069	3,978	4,530	▼4,530
	Construction		8,000	m³	552		
Stud	Material	EA	369	25	9,225	46,725	
	Construction		1,500	EA	37,500		

3.2 Discussion of manufacturability of the SC structure for the lifting plan

As mentioned previously, the economically effective stud interval was 250, based on which the materials were prepared, and the shop drawings of the SC structure were made in Figure 4.

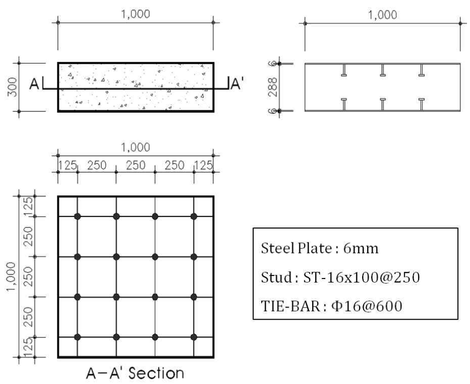

Figure 4. Unit module of SC structure

When the SC structure was applied, the thickness of the wall decreased by 18mm compared with a 300mm−retaining wall of the RC structure, but for convenience of manufacture the thickness of the wall was made to be 30mm. The retaining wall of the parking building, as shown in Figure 5, consisted of straight and curved sections, and the manufacturer of the SC structure and transport plan should be prepared individually. In addition, the size to be loaded on the cargo box of a truck is a minimum 2.3m and maximum 2.5m, and the product production by unit should not exceed a maximum of 2.5m.

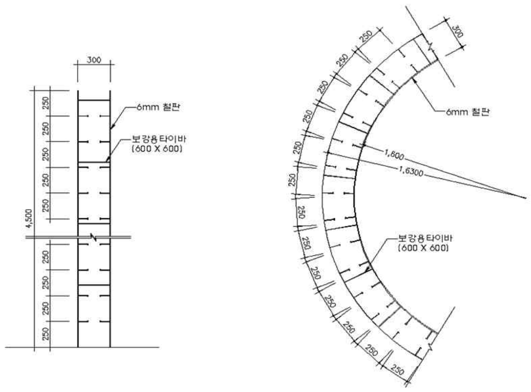

Figure 5. Straight and curved section of SC structure

Table 5 indicates that the materials of construction were calculated in consideration of the transport of the sizes of members applicable to the straight section of the parking ramp. It is manufactured to 2,500mmx4,500mm(width x height) after deliberation with the manufacturer, and the transportable sizes in the table were determined based on the specification of the steel frame by reflecting the number of steel plates and the number of studs and the weight of reinforcement hardware. A total of 360 studs were needed when the stud interval was set at 250, a total of 45 tie−bars were used for fixation when the distance was set at 600. The weight appeared to be about 1.1 tons on the basis of the size of a member of 2,500x4,500 for a 300mm−retaining wall.

Table 5. Material of construction (Straight section)

Contract	Element	Standard	Unit	Quantity	Unit Weight (kg)	Weight (kg)	note
W=2.5m H=4.5m	Steel plate	PL−6 2.500×4,500 (SS400)	Sheets	2	530	1,060	
	Stud	ST−16*100	EA	360	0.194	70	@250
	Tie−Bar	Φ16*300	EA	45			@600
Total Weight(kg)						1,130	

The curved section has a difference in the radius curvatures of the outer and inner section, and a different number or amount of materials is needed. However, the production and transport plan can be prepared under the same condition as a straight section. As indicated in Table 6, the weight ap− peared to be 1.1 tons on the basis of a member size of 2,500 x 4,500 for a 300mm−retaining wall, similar to that of straight section.

Table 6. Material of construction(Curved section)

Contract	Element	Standard	Unit	Quantity	Unit Weight (kg)	Weight (kg)	note
W=2.5m H=4.5m	Outside Steel plate	PL−6 2,498×4,500 (SS400)	Sheets	1	530	530	R=16m
	Inside Steel plate	PL−6 2,452×4,500 (SS400)	Sheets	1	520	520	R=16.3m
	Stud	ST−16*100	EA	360	0.194	70	@250
	Tie−Bar	F16*300	EA	45			@600
Total Weight(kg)						1,120	

3.3 Analysis of constructability through the discussion of construction duration of the SC structure

When engaging in RC structure construction, the construction schedule in 1−cycle was set from marking, placement of concrete after formwork and before marking. As shown in Figure 6, 1 cycle takes 22 days, with no consideration given to pos− sible rain delays. However, the actual construction duration for 1 cycle took 23 days when all the days are summed and then divided by the number of floors.

When the construction duration for 1 cycle was analyzed, the duration of form installation and rebar assembly scaffolding installation accounts for 50% of the entire process, and elaborate care is required, including horizontal bracing and scaffolding for the retaining wall support after assembling the framework of the retaining wall.

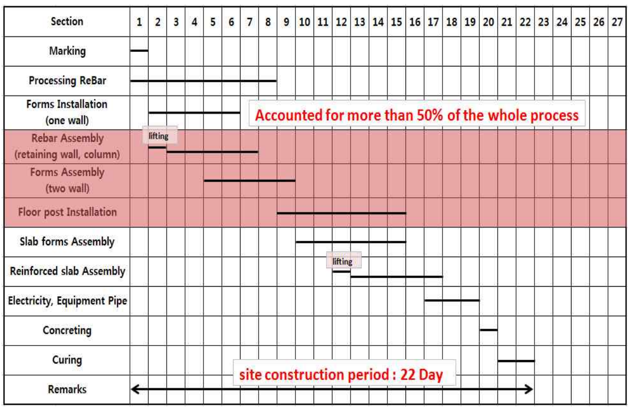

Figure 6. Construction schedule in 1-cycle (RC structure)

As shown in Figure 7, when the construction is finished by applying the SC structure, the construction duration for the installation of the structural wall can be reduced by 4 days because the SC structure can be manufactured in a transportable size at a factory, carried into the construction site, and then assembled with liftable members and installed immediately after marking, and the installation duration of rebars and form for the wall can be reduced. Therefore, the cycle can be reduced by 4 days, and the entire construction can be reduced by 27% compared with that for the RC structure.

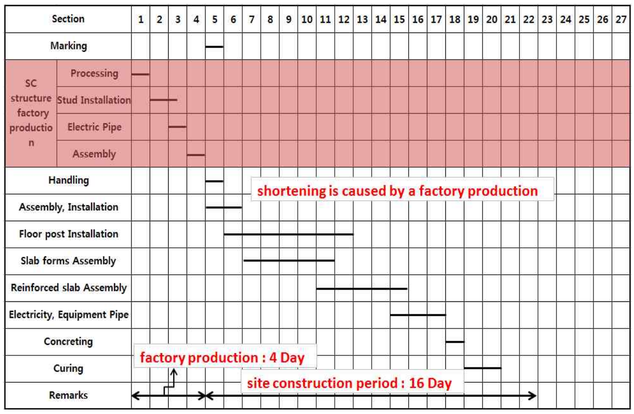

Figure 7. Construction schedule in 1-cycle (SC structure)

In addition, the SC structure can be factory manufactured in a modular form, helping to secure the quality, and if the formwork and rebar assembly process of the retaining wall are applied in the SC structure, the members can be simply assembled and installed at the site, resulting in a reduction of the construction duration for the installation of the retaining wall. The overhead cost can also be cut due to this reduction in the construction cost and construction duration.

3.4 Analysis of economic feasibility through an analysis of material amount of the SC structure

As shown in Figure 8, the construction cost was analyzed. This includes a detailed construction cost such as a breakdown of the individual costs for production, transport, assembly and installation of and lifting equipment for the size of the SC structure of 2,500x4,500 by dividing the costs for the straight and the curved sections. Table 7 indicates the unit construction cost by type. The construction cost for the straight section by module of the area of 11.25㎡ was KRW3,306,940. When it was converted based on the area of c it was KRW293,950.

The construction cost for the curved section by module of the area of 11.25㎡ was KRW3,593,890. When it was converted based on the area of 1㎡

was KRW318,568. In terms of transport the limitation to the construction cost calculation was reflected based on the section from Munmak, Gangwon-do to Gangnam, Seoul, and the cost for lifting equipment was calculated based on hydro crane. Connection of products was applied based on welding, and the power supply was calculated.

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품명	규격	단위	수량	재료비		노무비		경비		계		비고
				단가	금액	단가	금액	단가	금액	단가	금액	
Ⅰ. Type-1 직선FROM	1SET : W(1 2.5m) * H(4.5m)											
(1). 자재비		SET	1	1,642,000	1,655,640		-		-	1,642,000	1,655,640	
ⓐ. 철판(SS400)	PL-6t	톤	1.17	1,240,000	1,450,800		-		-	1,240,000	1,450,800	
ⓑ. STUD BOLT(자동)	M-16*100	EA	360	369	132,840		-		-	369	132,840	
ⓒ. 고정용 TIE BAR SET	Φ16*300	EA	48	1,500	72,000		-		-	1,500	72,000	
(2). 제작비		SET	1		-	751,000	799,200	438,000	470,100	1,189,000	1,269,300	
ⓐ. 인건비	현도/마킹/절단/사림/취부/사상마감	톤	1.06		-	270,000	286,200		-	270,000	286,200	
ⓑ. 소모자재비	Co2가스/산소/LPG/식대/기타	톤	1.06		-		-	54,000	57,240	54,000	57,240	
ⓒ. 장비비		톤	1.06		-		-	14,000	14,840	14,000	14,840	
ⓓ. 전력비		톤	1.06		-		-	12,000	12,720	12,000	12,720	
ⓔ. 공구손료		톤	1.06		-		-	5,000	5,300	5,000	5,300	
ⓕ. STUD BOLT 용접비		EA	360		-	900	324,000	600	216,000	1,500	540,000	
ⓖ. 고정용 TIE BAR SET 설치		EA	45		-	4,200	189,000	2,800	126,000	7,000	315,000	
ⓗ. 상차비	지게차	SET	1		-		-	38,000	38,000	38,000	38,000	
(3). 운반비	가공장-->현장(대전이북 기준)	SET	1		-		-	90,000	90,000	90,000	90,000	
(4). 이윤 및 관리비	10%	SET	1	164,000	164,000	75,000	75,000	53,000	53,000	292,000	292,000	
소 - 계	Ⅰ. Type-1 직선FROM	SET	1		1,819,640		874,200		613,100		3,306,940	

Figure 8. The process of estimating the unit cost of SC structure manufacturing and construction

Table 7. The cost of manufacturing and construction of SC structure

Name	Standard	Unit	Quantity	Price (won)			
				material cost	labor cost	cost	sum
Straight Section	W(2,5m)×H (4.5m)	Set	1	1,819,640	874,200	613,100	3,306,940
Curved section	W(2,5m)×H (4.5m) R=16,150	Set	1	1,787,240	822,400	974,250	3,583,890
Total	direct construction cost			3,606,880	1,696,600	1,587,350	6,890,830

For the comparison of the cost items drawn above, the construction cost items for the RC structure were derived. The conventional technique, which is the RC structure, has many problems with supply and demand due to frequent rises in payroll cost and a lack of skilled laborers. Various techniques have been applied to finish the construction within the construction duration, and the system forms are applied at the installation of form. The rebar is prepared by cutting and producing at a processing factory so that it can be assembled and then installed at the site. Therefore, the amount of cost by item was calculated below. The D19mm-rebars were placed from the 6th to the 4th basement levels at intervals of 150 while the D16mm-rebars were placed from the 3rd to 1st basement levels at intervals of 150. The D19mm-rebars required for a unit area of 1㎡ weighed 63kg while the D16mm-rebars weighed 43.68kg. The economic feasibility analysis was performed based on D19mm. The form for the parking ramp structure construction was calculated based on the Euroform and the rebar processing was also based on processing at a factory. The lifting of form and rebar accounts for a large portion of the steel frame construction, and operating costs were calculated based on the monthly rent of a 120-ton tower crane. The monthly rent of the tower crane was calculated based on 25 working days a month and 8 hours a day. In the steel frame construction, 70% of lifting equipment was operated for the installation of steel frame, transport and lifting of materials for the steel frame construction. Of the 70% of operating, 30% accounted for the transport of materials for form and rebar materials for an assembly. Here, the unit cost per unit area(KRW/㎡) was calculated using the formula: monthly rental(25days×0.7×0.3)/10 ㎡(daily labor capacity). The construction cost per 1㎡ for an RC structure was calculated based on the price information list, and Table 8 shows calculation results of the construction cost.

Table 8. The cost of manufacturing and construction of RC structure

Contents		Unit	Unit Price (won)	Price (Won/㎡)	Note
marking		㎡	500		
steel pipe strut (under 5m)		㎥	1,400	6,300	H=4,5m
steel pipe support		㎥	22,000		
plywood form(3회)		㎡	28,000	56,000	
plywood form(surface)		㎡	29,000	58,000	
plywood form(slope)		㎡	29,000	58,000	
material cost of rebar		Ton	761,000	38,050	63kg/㎡
Shop assembling for rebar (Including the carrying)		Ton	40,000	2,520	63kg/㎡
setting up of steel –bar(normal)		Ton	178,000	11,214	63kg/㎡
setting up of reinforcing bar		Ton	210,000	10,500	
Rental fee of crane (12Ton)		Month	19,000,000	37.240	won/㎡
profit		10%		16,000	
Total	Straight Section	–	–	177,217	–
	Curved section	–	–	180,817	–

Based on the results of a comparison between SC and RC structures for the retaining wall of a parking building, the SC structure is shown to be more expensive by about 166% for the straight section and by about 176% for the curved section compared to the RC structure. Therefore, in terms of direct construction cost, the SC structure is 1.6–1.8 times more expensive. However, in the above analysis the cost reduction factors were not included, such as reduction in overhead cost due to a reduction of about 27% in construction duration, reduction in the wall thickness, and arrangement at the site. In addition, the stud interval ratio for the SC structure resulted in a reduction in the wall thickness depending on the stud interval ratio, but the effect of cost reduction in concrete material cost and construction cost was minimal, and the wall was made in 300mm with no consideration of those factors. Taking into account that the economic feasibility was analyzed based on the fact, the costs would be slightly lower than those calculated.

Table 9. The unit price-comparison Of SC structure and RC structures

Contents		Price per unit area (Won)	Analysis of rate	Note
Straight Section	SC	293,950	166%	Un-reflected of duration shortening effect
	RC	177,217	100%	
Curved section	SC	318,568	176%	
	RC	180,817	100%	

4. Conclusion

The SC structure is expected to be applicable to the core wall or the shear wall of the vertical retaining wall in a stair hall of a general structure, and the findings below are the results of an analysis of construction duration and economic feasibility when the SC structure was applied to a parking building.

1) If an SC structure was designed to have the maximum load and load stress equivalent to those of the RC structure, the wall was decreased in thickness. However, the reduction in the amount of concrete compromised the increase in the number of studs from the economic perspective, and it is more economical to use a fewer number of studs.
2) When the SC structure was applied to the wall installation for the RC structure, the SC structure was pre-manufactured at a factory and then installed at the site after it was assembled as members that can be lifted, and the rebar placement and form installation for the wall can be reduced, resulting in a 27%~30% reduction of construction duration.
3) In the comparison of construction cost between RC and SC structures, the manufacturing and installation cost of the SC structure

was shown to be approximately 1.6–1.7 times higher compared with the RC structure. However, a 27%–30% reduction in construction duration could bring about a reduction in overhead cost, and it was also possible to reduce the arrangement cost of form and material loss further compared with the RC structure. Therefore, an accurate analysis of cost reduction factors should be performed for a more deliberate understanding of constructability and economy.

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