NEW DESIGN STANDARD FOR CIVIL ENGINEERING STRUCTURES BASED ON THE MINIMUM LABOUR CONCEPT

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In Japan, design standards for civil engineering structures have been based on the minimum material concept since the 1960s, because material costs were relatively higher than labour costs at that time. Because labour costs are now much higher relative to material costs, the Ministry of Construction of Japan recently reviewed the design standard, replacing the minimum material concept with the minimum labour concept.

The cost estimation system established by the Ministry of Construction was applied to various kinds of civil engineering structures to analyse the effective factors governing total cost taking into account structural safety. It was found that the simplification of structural shape, standardisation of materials, and application of precast concrete result in reduction of total costs, although more materials are required than before. The new design standard for civil engineering structures was proposed in terms of total cost reduction.

Keywords: cost reduction, design standard, minimum labour Japan, price indices

INTRODUCTION

Since 1965, the Ministry of Construction of Japan has standardised the design of civil engineering structures to provide standard designs so that public civil engineering projects are executed efficiently. Because the cost of concrete, steel reinforcing bars, and other materials was relatively higher than the cost of labour, standard designs were prepared based on the minimum material concept intended to minimise the materials used. When a civil engineering structure has been designed in line with the minimum material concept, its shape and reinforcement tend to be complex and its construction requires many steps by experienced craftsmen.

Since the 1960s, workers' wages have increased more than the unit cost of materials. To take the construction of a cast-in-place reverse T-shaped retaining wall as an example of the effects of this trend, the percentage of total construction costs accounted for by the labour cost would have been less than 30% in 1965, but had risen to about 60% in 1995. It is also forecast that the declining birth rate and ageing of the population in Japan will result in a future shortage of experienced form workers and steel reinforcing bar workers accompanied by a rise in the average age of those available.

Under these circumstances, the minimum material design concept applied to the standard designs must be replaced by the minimum labour concept in order that

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projects are executed efficiently. This report is an outline of the proposal and economic evaluation of construction improvement measures for cast-in-place box culverts and reverse T-shaped retaining walls that are typical structures based on standard designs.

CONVENTIONAL STANDARD DESIGNS

Outline of standard designs

Standard designs establish standardised structural specifications based on standards governing public projects in Japan and are used as working drawings for public civil engineering works. When this provides a standard structure, projects can be conducted efficiently because it is not necessary to design each structure separately.

Standard designs are provided for the following structures, almost all of which are relatively small scale. When a large-scale structure or a small-scale structure that must account for the scenic appearance of its site is to be constructed, it is specially designed without applying a standard design.

(1) Earth work structures: box culverts, retaining walls

(2) River structures: sluice ways

(3) Grade separated crossings: pedestrian bridges, pedestrian tunnels

(4) Bridges: bridge abutments, bridge piers, simple bridges (PC, Steel)

Characteristics of conventional standard designs

Conventional standard designs have established the shape and dimensions of structures and their steel reinforcement specifications based on the concept called the minimum material: an approach that minimises the quantity of concrete, steel reinforcing bars, and other materials used.

The characteristics of structures based on standard designs are introduced taking a cast-in-place reverse T-shaped retaining wall as an example.

The shape of the structure

Figure 1 shows the standard cross-section of a reverse T-shaped retaining wall; both the vertical wall and the footing are tapered members.

This is done to provide the members with nonuniform cross sections according to the scale of the generated stress in order to minimize the cost of the concrete materials used to make the vertical wall and footing.

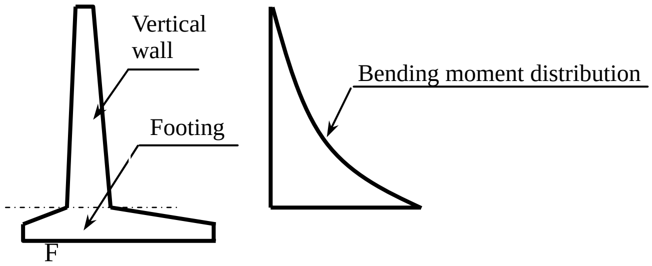


Figure 1: Normal Cross Section Shape of a Reverse T-shaped Retaining Wall

Reinforcing bar arrangement

Because of the complexity of the structure, the processed shape of the steel reinforcing bars is complicated and also tends to be widely varied. In the design of the section of the principal members, the effective height of the member is large in comparison to the longitudinal reinforcement. Therefore, the distribution reinforcement is installed outside the longitudinal reinforcement and the member is thin, resulting in a dense arrangement of the steel reinforcing bars.

NEW STANDARD DESIGN

Background and perspectives

The following is the background to the review of the design standards

The unit costs of concrete, steel reinforcing bars, and other materials have declined relative to the unit cost of labour, increasing the percentage of total construction costs accounted for by labour costs (see Figure 2 and Figure 3).

The ageing of experienced workers and skilled workers able to perform complex processes and a general decline in workers' skills have become conspicuous problems.

The constructability of civil engineering structures must be improved.

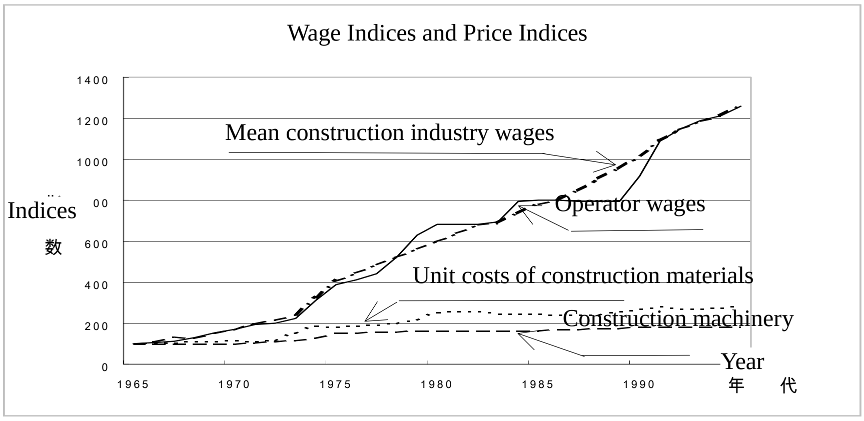
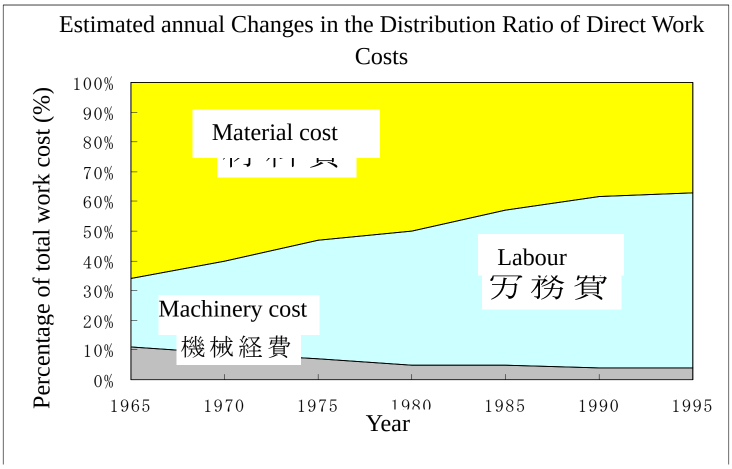


Figure 2: Wage indices and price indices (Source: Economic Affairs Bureau of the Ministry of Construction, Bank of Japan Wholesale Price Index, Secretariat of the Minister of Labour, Policy Planning and Research Department, Annual Survey of Monthly Labour Statistics)

Figure 3: Changes in the Distribution Ratio of Work Costs



(For this estimation, it was assumed that only the unit costs of construction machinery, wages of labour, and construction materials vary and that the materials standards governing concrete, steel reinforcing bars, etc. and the way they are executed has not changed.)

The following three objectives were established as part of the review of the standard design in order that work be performed with fewer and less experienced workers while achieving safer working conditions on the premise that the work guarantees safety, functionality, and quality, etc. required by structures that is equal to or higher than in the past.

Objective–1: making the shape of the structure as simple as possible

Objective–2: promoting the standardisation and specification of materials used and principal members

Objective–3: promoting the construction of precast concrete structures

On the economic side, simplifying the shapes of structures does tend to increase materials costs somewhat, but by cutting the number of workers at the site, it lowers labour costs by an amount greater than the material cost increase, bringing an overall reduction in work costs (see Figure 4).

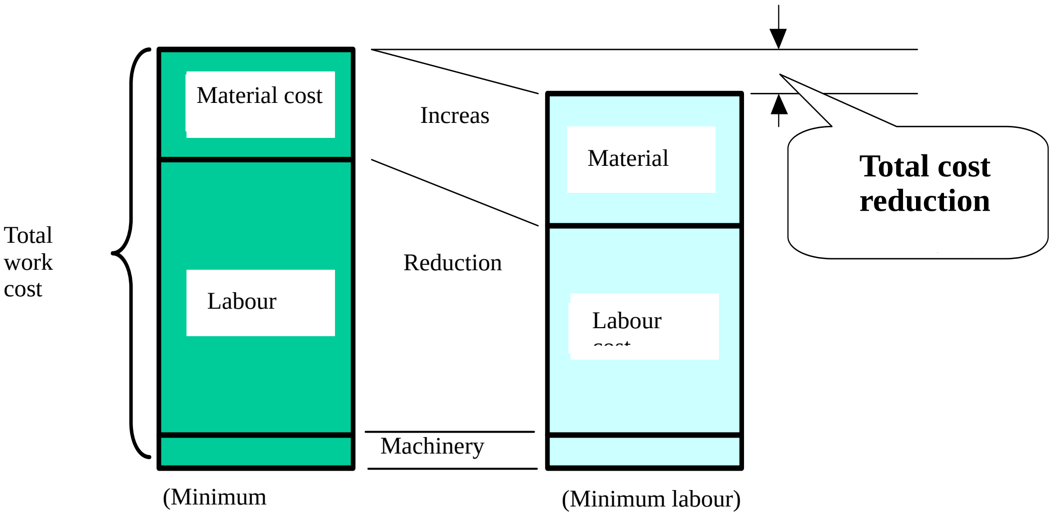


Figure 4: Relationships of distribution ratios of work cost

PROPOSED CONSTRUCTION IMPROVEMENT MEASURES

The following are measures intended to rationalise the construction of box culverts and of reverse T-shaped retaining walls (see Table 1).

Table 1: Box culvert and retaining wall construction improvement methods

Standard Design Review Perspective	Specific Measures Expected to Improve Constructability	
	Box Culvert	Reverse T-shaped Retaining Wall
[Objective 1] Simplifying structure shape	Eliminating the bottom haunch	Eliminating the taper on the top surface of the footing Simplifying the vertical wall shape
[Objective 2] Standardisation and specification of materials used and principal members	Reinforcement using standard size steel reinforcing bars Changing the location of the distribution reinforcement	- ditto - ditto Eliminating the variation of the section of the longitudinal reinforcement of the vertical wall
[Objective 3] Using precast concrete structures	Concentrating standardised products	– ditto

[Objective 1]: Simplification of structure shape

Eliminating the bottom haunch

This measure modifies the box culvert standard design by eliminating the bottom haunch that must be installed on the bottom surface of the form (see

Figure 5). But to eliminate the haunch from a structure, the section of the members that form the corners where the haunch was eliminated are designed with extra stress (the allowable bending compressive stress of the concrete is reduced by 25%).

Because the haunch formerly installed on the bottom surface of the form has been eliminated, in addition to increasing overall work efficiency, it is no longer necessary to inspect the lower haunch during concrete pouring.

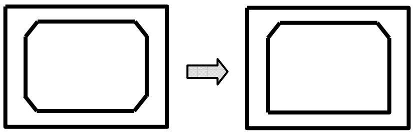


Figure 5: Elimination of the bottom haunch of a box culvert

(2) Elimination of the taper on top of a footing

This measure eliminates the taper on the top surface of the footing of a reverse T-shaped retaining wall.

In the past, the top surfaces of footings have been tapered according to the state of the bending moment distribution.

In addition to simplifying the concrete finishing work on the top surface of the footing, it is also counted on to make the overall work more effective by allowing the use of only one kind of erection bar. And because the top surface of the footing is horizontal, the foundations of scaffolding assembled on top of the footing are more stable than before, making the construction safer (see Figure 6).

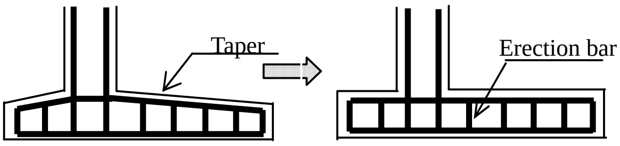


Figure 6:Elimination of the taper on the top surface of the footing of a reverse T-shape retaining wall

(3) Simplification of the vertical wall shape

This measure simplifies the section shape of the vertical wall of a reverse T-shaped retaining wall to a rectangular shape (Figure 7).

In the past, the gradient of the vertical wall was set according to the distribution of the bending moment.

In addition to simplifying form construction, only one kind of erection bar is required. And because the distance from the scaffolding to the vertical wall is constant, scaffolding no longer needs overhanging parts, is easier to assemble, and it is safer.

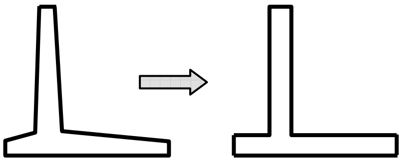


Figure 7: Simplification of the vertical wall shape of a reverse T-shape wall

[Objective 2]: Standardisation and specification of material used and principal members

(1) Reinforcement using standard size steel reinforcing bars

Reinforcement using standard size steel reinforcing bars calls for the use of standard size reinforcing bars whose lengths are, in principle, stipulated in 50 cm units. The steel reinforcing bar is adjusted by the lap splice and anchor sections (see Figure 8).

In the past, when two or more steel reinforcing bars were installed using the lap splice method, the stipulated lap splice length was controlled in units of 1 mm. This required a great deal of steel reinforcing bar cutting work.

Reducing the steel reinforcing bar cutting work results in safer and more efficient work. It also simplifies the steel reinforcing bar lap splice length and anchor length control work.

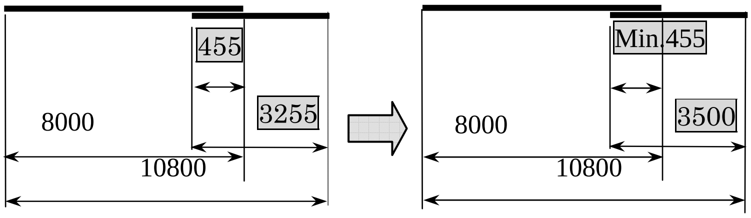


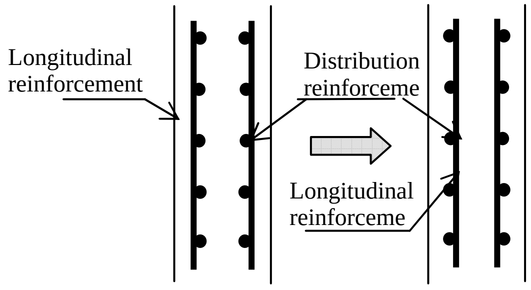
Figure 8: Reinforcement using standard size steel reinforcing bars

(2) Changing the location of the distribution reinforcement

The measure moves the distribution reinforcement outside of the longitudinal reinforcement to make the steel reinforcing bar assembly work more efficient and to account for distribution of the stress etc. (see Figure 9).

In the past, the superiority of design calculations that increase the effective height of the steel reinforcing bars was emphasised over the steel reinforcing bar assembly work properties, and the longitudinal reinforcement was installed outside of the distribution reinforcement.

Figure 9: Changing the location of the distribution reinforcement



This change in the location of the distribution reinforcement permits the simplification of the steel reinforcing bar assembly procedure

Eliminating the variation of the section of the longitudinal reinforcement of the vertical wall

This measure, in principle, eliminates the variation of the section of the longitudinal reinforcement in the vertical wall of a reverse T-shaped retaining wall (see Figure 10).

In the past, the section of the longitudinal reinforcement was varied according to the state of the distribution of the bending moment of the vertical wall.

The reduction in the number of processed shapes of the longitudinal reinforcement reduces the quantity of labour required to process and to assemble the steel reinforcing bars.

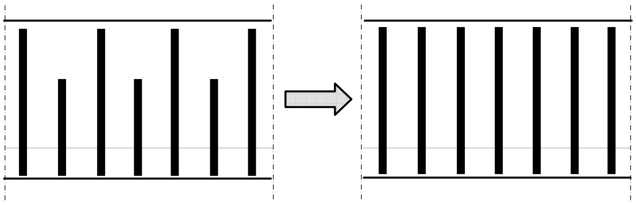


Figure 10: Elimination of the variation of the section of the longitudinal reinforcement of the vertical wall

[Objective 3]: Precast concrete structures
This measure groups the standards for multiple sections (products) based on fixed rules.

CORROBORATIVE STUDY OF CONSTRUCTION IMPROVEMENT MEASURES BY MODEL WORKS

Model works were executed to evaluate the labour saving effects and economic benefits of the above construction improvement measures. This study gave the following results.

Outline of the model works

(1) Number of the model works

The study included the construction of 45 model works: 18 box culverts, 10 reverse T-shaped retaining walls, 9 T-shaped bridge abutments, and 8 cantilever bridge piers.

(2) Study of the model works

The study of the model works included the quantities of concrete, form, and steel reinforcing bar work plus the number of workers by worker category and the operating hours of the construction machinery in order to evaluate the construction site labour saving effects and cost reduction effects.

RESULTS OF THE EVALUATION OF THE CONSTRUCTION SITE LABOR SAVING EFFECTS

The index used to evaluate the construction site labour saving effects was considered to be the number of workers required to execute unit quantities of concrete, form, and steel reinforcing bar work.

In other words, the number of workers required by structural specifications of the conventional standard design that has already been studied was compared with the number of workers based on the model works in order to study the construction site labour saving effects. The labour saving rate was obtained by a construction cost conversion calculation because the workers included a number of worker categories (supervisors, form workers, steel reinforcing bar workers, etc.)

Results of the analysis of concrete work

Table 2 presents the results of the analysis of the labour saving effects for concrete work. The data for actual work was not accurately obtained, resulting in scattering of the analysis results. It is assumed that for this reason, the structure categories were biased n each casting volume per day category.

Table 2: Results of the analysis of the labour saving effects on concrete work (per 10 m^3)

Casting Volume Per Day	Worker Category	Conventional Standard Design			Model Work Results			(1- /) ×100 (%)
		Workers (People)	Unit Labour Cost (Yen/Worker)	Labour Cost (Yen)	Workers (People)	Unit Labour Cost (Yen/Worker)	Labour Cost (Yen)	
Less than 50 m^3	Supervisor	0.15	25000	23408	0.12	25000	17876	24
	Special worker	0.42	20900		0.24	20900		
	Ordinary worker	0.64	17000		0.58	17000		
50 m^3 or more but less than 100 m^3	Supervisor	0.11	25000	18264	0.11	25000	20290	-11
	Special worker	0.36	20900		0.40	20900		
	Ordinary worker	0.47	17000		0.54	17000		
100 m^3 or more but less than 300 m^3	Supervisor	0.07	25000	12872	0.07	25000	13318	-3
	Special worker	0.28	20900		0.22	20900		
	Ordinary worker	0.31	17000		0.41	17000		
Simple mean								3

Results of analysis of the form work

Table 3 shows the results of the analysis of the labour-saving effects on form work. The simple mean value of the labour-saving rate is 24%, far higher than that for concrete work and for steel reinforcing bar work discussed below. This is believed to be a result of the big contribution to the reduction of form work labour by the elimination of the bottom hunch from box culverts and other simplifications of structure shapes.

Table 3: Results of the analysis of the labour saving effects on form work (per 100 m^2)

Height Installed	Worker Category	Conventional Standard Design			Model Work Results			(1- /) ×100 (%)
		Workers (People)	Unit Labour Cost (Yen/Worker)	Labour Cost (Yen)	Workers (People)	Unit Labour Cost (Yen/Worker)	Labour Cost (Yen)	
Less than 4 m	Supervisor	3.6	25000	693540	3.4	25000	528600	24
	Form worker	18.2	22700		14.0	22700		
	Ordinary worker	11.2	17000		7.4	17000		
4 m or more	Supervisor	3.2	25000	639340	3.0	25000	489700	23
	Special worker	18.2	22700		14.0	22700		
	Ordinary worker	8.6	17000		5.7	17000		
Simple mean								24

Results of the analysis of the steel reinforcing bar work

Table 4 shows results of the analysis of the labour saving results on the steel reinforcing bars work. The mean average of the labour saving rate is 16%.

Table 4: Results of the analysis of the labour saving results on steel reinforcing bar work (per 1 ton)

Casting Volume Per Day	Worker Category	Conventional Standard Design			Model Work Results			(1- /) ×100 (%)
		Workers (People)	Unit Labour Cost (Yen/Worker)	Labour Cost (Yen)	Workers (People)	Unit Labour Cost (Yen/Worker)	Labour Cost (Yen)	
D13 or less	Supervisor	0.6	25000	113000	0.52	25000	96700	14
	Steel reinforcing bar worker	2.9	20900		3.49	20900		
	Ordinary worker	2.2	17000		0.63	17000		
D16 to D25	Supervisor	0.5	25000	95000	0.39	25000	71700	25
	Steel reinforcing bar worker	2.4	20900		2.58	20900		
	Ordinary worker	1.9	17000		0.47	17000		
D29 to D32	Supervisor	0.3	25000	55500	0.26	25000	49700	10
	Steel reinforcing bar worker	1.4	20900		1.80	20900		
	Ordinary worker	1.1	17000		0.33	17000		
Simple mean								16

RESULTS OF THE ANALYSIS OF ECONOMIC EFFECTS

Evaluation procedure

The quantities of concrete, form work, and steel reinforcing bar work were computed by performing detailed design based on the conventional standard design and on the construction improvement measures.

The construction cost was estimated based on Table 2 to Table 4 and on the quantities referred to above.

Evaluation results

Table 5 and Table 6 show results of evaluations of the economic effects for the box culvert case and the reverse T-shaped retaining wall case. As shown in Table 2, the results of the analysis of the concrete work were scattered, but because the material costs are far higher than the labour costs in the concrete work case, it has almost no influence on the evaluation of economic effects described below.

The same table shows the distribution ratios of the material cost, labour cost and machinery cost assuming that the total value of the construction cost based on the conventional standard design equals 100%. In both the box culvert and the reverse T-shaped retaining wall cases, overall, the percentage decline in the labour costs is greater than the percentage increase in the material cost, revealing that the minimum labour concept is also beneficial from the economic perspective.

Table 5: Results of the evaluation of the economic effects for box culverts

Case		Material Cost (%)	Labour Cost (%)	Machinery Cost (%)	Total (%)	Cost Reduction Percentage (−) (%)
B=2m ×H=2 m	Conventional standard design	29	69	2	100	11
	Construction improvement design	30	57	2	89	
B=4m ×H=5 m	Conventional standard design	32	65	3	100	4
	Construction improvement design	36	56	3	96	

B=6m ×H=5 m	Conventional standard design	37	59	4	100	6
	Construction improvement design	41	49	4	94	

This report omits the results of the evaluation of the economic effects for the case of a reverse T-shaped bridge abutment and a cantilever bridge pier, but as in the box culvert cases, good evaluation results were obtained.

Table 6: Results of the evaluation of the economic effects for reverse T-shaped retaining walls

Case		Material Cost (%)	Labour Cost (%)	Machinery Cost (%)	Total (%)	Cost Reduction Percentage (−) (%)
H=3m	Conventional standard design	31	67	2	100	8
	Construction improvement design	33	56	3	93	
H=6m	Conventional standard design	35	61	4	100	9
	Construction improvement design	38	49	4	91	
H=9m	Conventional standard design	41	56	3	100	-2
	Construction improvement design	48	51	3	102	

CONCLUSIONS

This change to design principles that emphasises constructability has been proposed as a way to reduce costs in light of the fact that in recent years, the economic environment has been transformed by a rise in labour costs relative to material costs. And as a low birth rate and the ageing of the population bring a steady decline in the number of experienced form workers and steel reinforcing bar workers, steps to improve construction at construction sites will be an important theme in the future.

The following is a summary of the content of this report.

The construction improvement measures that have been proposed are broadly categorised as those related to the shapes of structures and those related to the installation of steel reinforcing bars. The structure shape related measures are shape simplification measures: elimination of tapering of the vertical walls and footings of retaining walls and the elimination of the bottom haunches of box culverts. Those related to steel reinforcing bars include simplification of the processed shape and the use of standard size bars.

Corroborative experiments were performed based on model works to study the labour saving effects of the proposed measures on concrete, form, and steel reinforcing bar work. The results were almost identical for the concrete work, but labour saving rates of 24% and 16% were confirmed for the form work and steel reinforcing bar work respectively.

Estimates of the economic effects based on these results permit the conclusion that these measures are economically effective under normal conditions, although the extent of the effects vary according to the type and scale of the structure.

And in addition to cutting construction costs, a qualitative evaluation shows that these measures can improve construction safety and shorten construction periods.