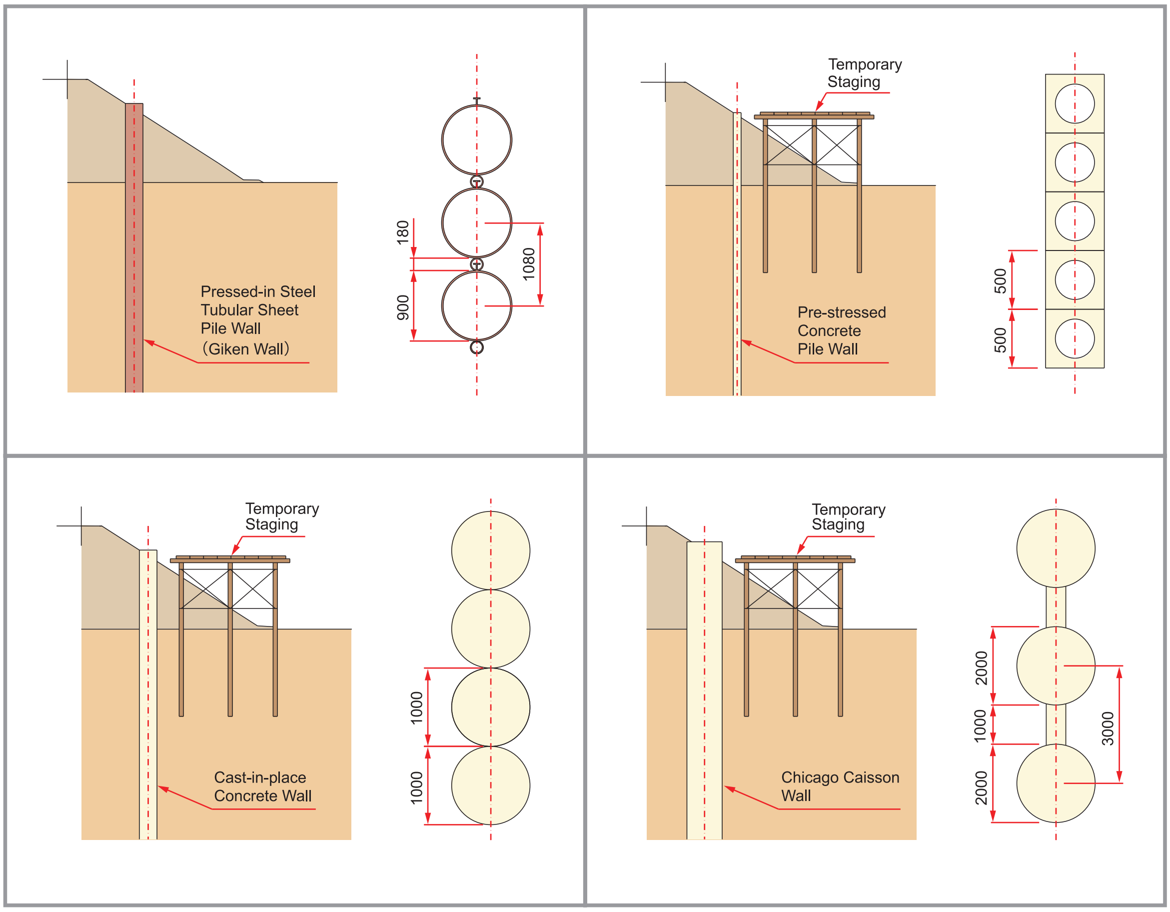
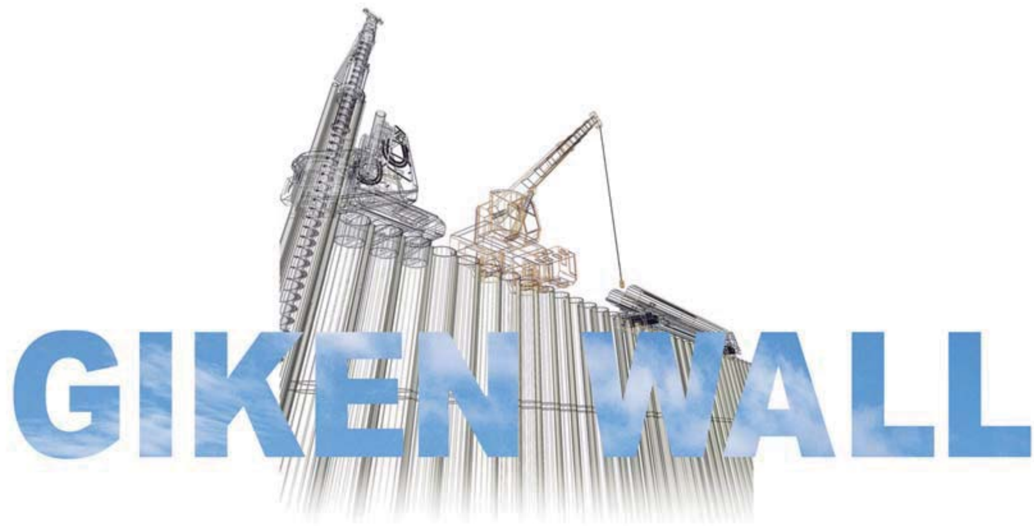
Method Comparison for Construction of Retaining Wall on Slope Embankment



Construction Solutions
GIKEN



Contents

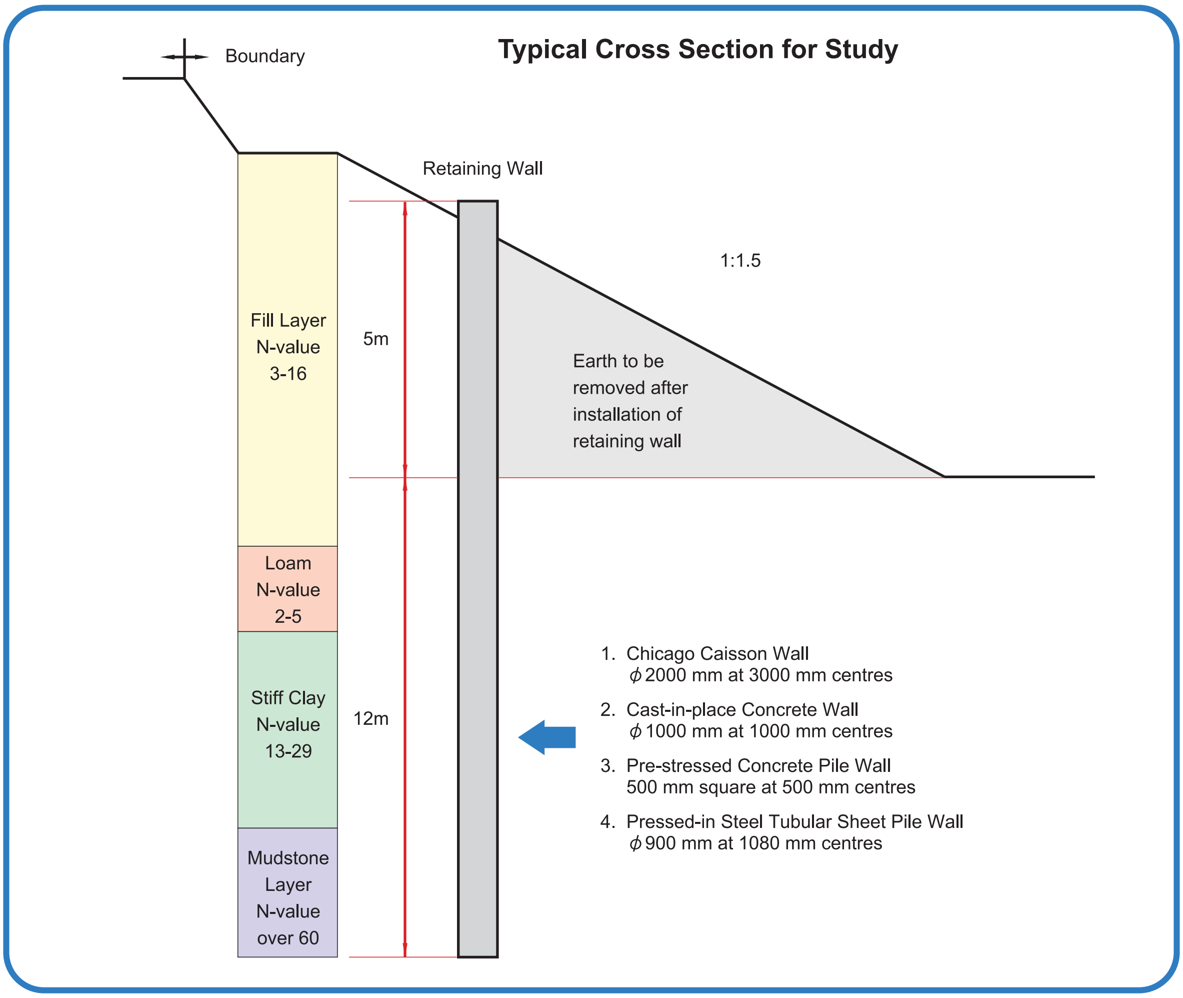
General

Several construction methods were studied for the construction of the retaining structure on the embankment slope to widen the current road to assess the cost, time and life cycle parameters. Several restrictions were imposed for this study taking into account the actual site conditions; i.e., (1) Impact or vibration hammer could not be used from the environmental restrictions, (2) earth anchor could not be installed due to the limited backspace of the site, (3) and the deflection of the top of wall should be less than 5 cm. Among several possible methods the four following methods were selected for detailed.

1. Chicago Caisson Wall with Concrete Lagging	(ϕ2000 mm at 3000 mm centres)
2. Cast-in-place Concrete Wall (All Casing Method)	(ϕ1000 mm at 1000 mm centres)
3. Pre-stressed Concrete Pile Wall	(500 mm square at 500 mm centres)
4. Pressed-in Steel Tubular Sheet Pile Wall (Giken Wall)	(ϕ900 mm at 1080 mm centres)

Typical Cross Section for Study

A typical cross section for study is shown on right hand side.



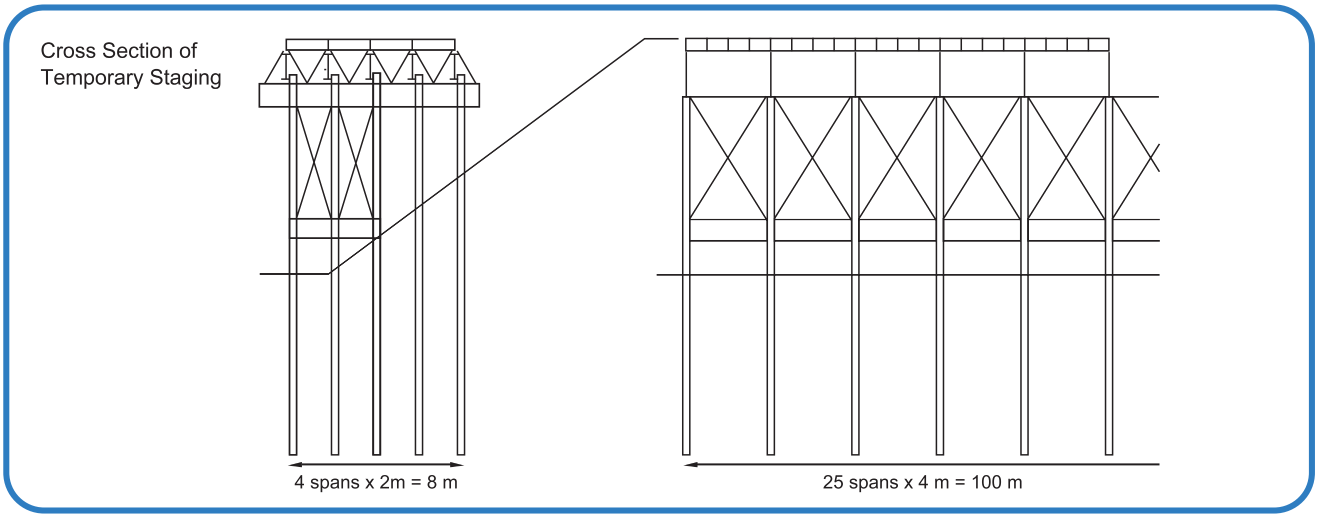
Assumption on Study

Four methods were studied to evaluate cost, time and life cycle parameters. The following assumptions were made for the study, i.e.,

1. Wall length: 100 m
2. Wall depth: 17 m (5 m above ground surface, 12 m below ground level)
3. Construction time is actual working days and does not include any days lost due to weather, Sundays or holidays.
4. Cost estimation was made based on the standard method of estimation which is established by the Ministry of Land Infrastructure and Transport in Japan.
5. Material and manpower costs are the market prices prevailing now in Japan.
6. Steel is fabricated at factory and transported to site (within 50 km).
7. Concrete will be transported from the batching plant 10 km from site with mixer truck of 4.5 m^3/truck.
8. Other construction materials and equipments can be mobilized from sources within 50 km of the site.
9. Disposal area is located around 15 km from the construction site.
10. All methods except pressed-in steel tubular sheet pile wall require temporary staging where construction materials and equipment can be placed and stored during construction period.

Temporary Staging

Temporary staging was designed so as to secure the safe working conditions under the live load of 75 % of 100 tons (equipment load) applied to one caterpillar. Width of stage is 8 m considering the max. length of equipment of 7.08 m. The cross-section of the temporary staging is shown in the following sketch.



The material list for temporary staging is summarized in the following table. The temporary staging can be erected at a rate of 4 days per 20 m and therefore 20 days is required to complete erection of temporary staging for 100 m length. Removal of temporary staging can be estimated as 15 days.

Material List for Temporary Staging

Name		Specification	Unit	Quantity
Cover Plate		1000x1000x208	ton	159
Main Girder		H588x300x13x20	ton	75
Girder Support		C380x100x13x20	ton	32
H pile		H350x350x10x19	ton	257
Bracing		L75x75x6	ton	7
	for prevention of overturn		ton	3
Horizontal Joint		C150x75x9x12.5	ton	20
Bolt, Nut, Washer	for Girder Support	M27x80, 1500 sets	ton	3
	for Main Girder	M24x80, 500 sets		
	for Horizontal Joint	M24x70, 900 sets		
	for Bracing	M22x70, 1300 sets		
Joint Plate	for Horizontal Joint	L100x100x10	ton	1
	for Bracing			
Total				**557**

Construction Methods

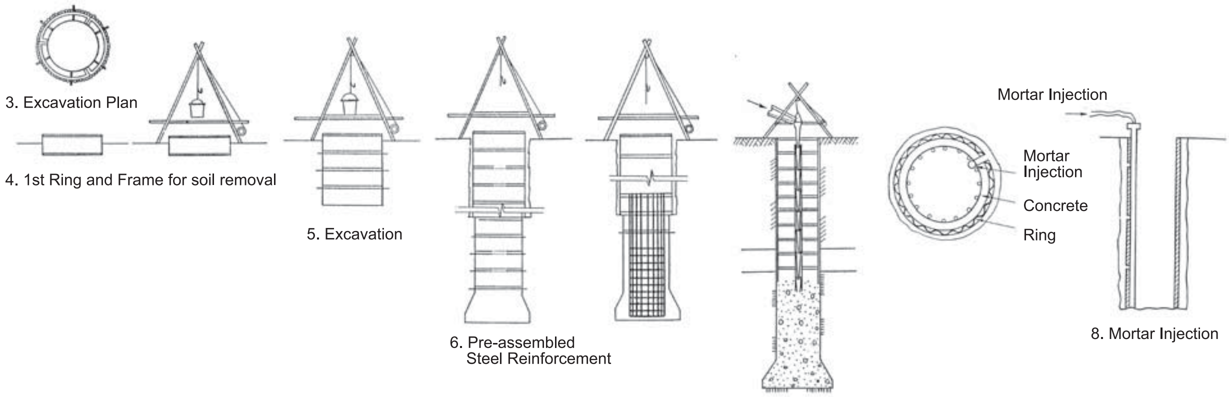
Chicago Caisson Wall

Chicago caisson consists of cast in place concrete piles, systematically excavated below the bottom of unit, descending to the final depth using either a casing tube or a combined steel plate with ring frame. Usually, the top and bottom are open during installation. There are two types of excavation, i.e., manual excavation for smaller sizes (up to 2.5 m in diameter) and excavation by clamshell type bucket or hammer grab for large diameter caissons.

Features of this method are (1) low noise and vibration, (2) large diameter pile can be constructed, (3) it is possible to excavate hard ground and to remove rocks encountered during excavation. On the other hand the method is not suitable for the loose sandy soil and soft clayey soil and the very permeable layer where it is very difficult to dewater from within the caisson. Suitable countermeasures will possibly be needed to protect the wall from collapsing for the loam appeared from 8 to 10 m in depth. We did not consider any time and cost required for the countermeasures in this study. Followings are the sequence of work for the method.

1. Mobilization of all necessary equipment and materials.
2. Erection of temporary staging
3. Setting out and excavation approximately 60 cm for 1st ring.
4. Setting up frame for removal of excavated soil
5. Excavation manually with setting rings and continuous excavation up to designated depth.
6. Cleaning bottom of excavation and installation of pre- assembled steel reinforcement.
7. Placement of tremie concrete.
8. Filling mortar in the space between ring wall and soil.

Chicago Caisson Wall

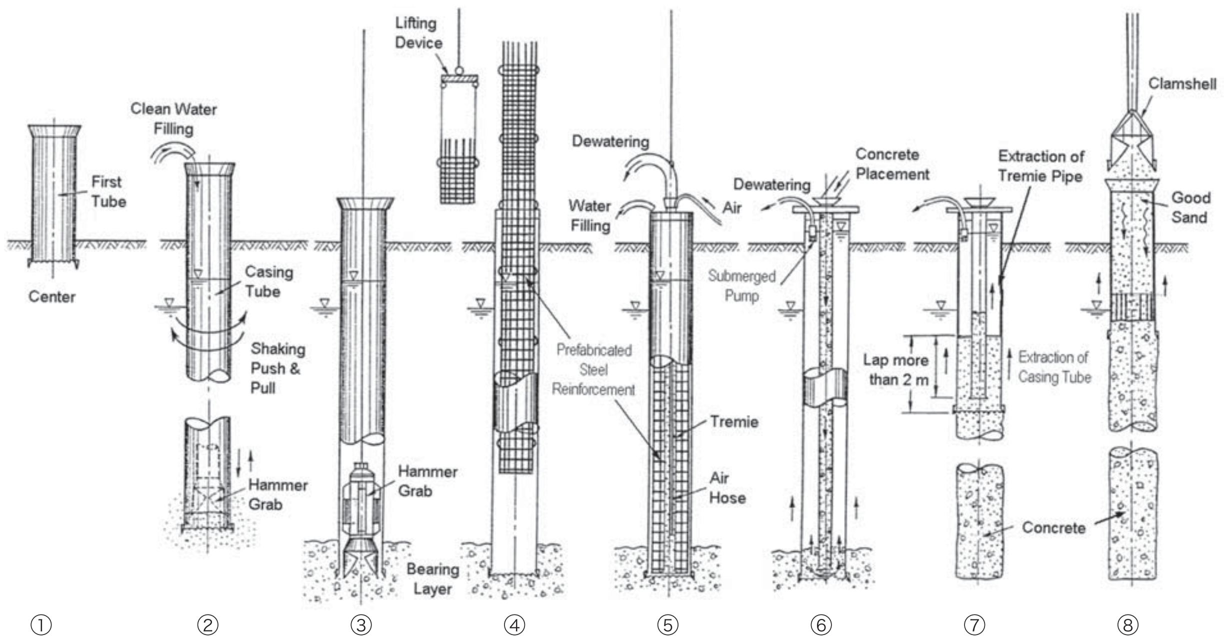


Cast-in-place Concrete Wall (All Casing Method, ϕ1000 mm at 1000 mm centres)

Excavation carried out by hammer grab after installing casing tube into ground by shaking movement (vibrating or oscillating) of the tube. The following is the typical procedure for this method.

1. Setting machine in the first location and 1st casing tube is set correctly to the designated position.
2. Casing tube is jointed and pressed in by (an oscillating / a vibrating) a shaking movement. Excavate the soil inside tube by hammer grab filling water into the casing to prevent boiling and heaving. Excavation is proceeding by repeating the process. No water filling is required if boiling and/or heaving are not expected.
3. After reaching the designated depth excavated bottom will be cleaned.
4. Install pre-fabricated steel reinforcement into casing pipe.
5. Install tremie pipe for concrete placement.
6. Tremie concrete will be placed and water replaced with concrete is removed by pump.
7. Casing pipe and tremie are extracted while concreting up to designated elevation.
8. Filling good sand into voids

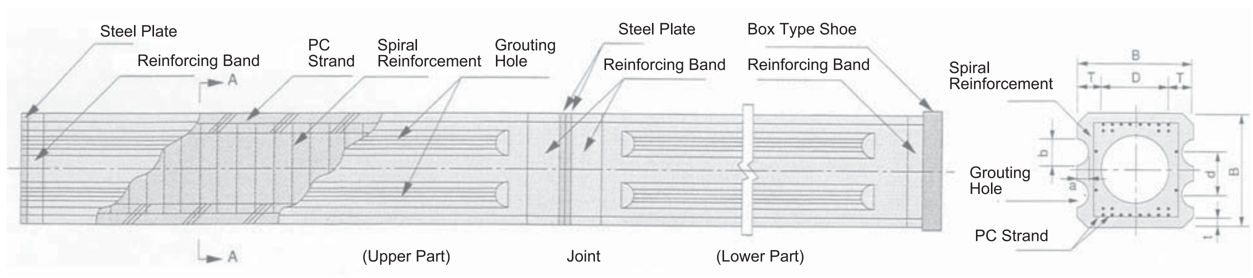
Cast-in-place Concrete Wall



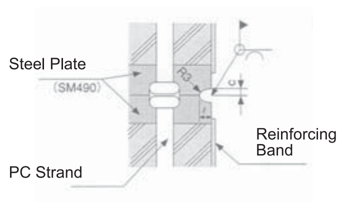
For the ground with lower water level, it is difficult to extract casing pipe. Firm staging is required to work safely against the load of heavy dead weight of machine and the load applied when extracting casing pipe.

Pre-stressed Concrete Pile Wall (500 mm square with the voids in the center)

Pre-stressed concrete pile is fabricated at factory using high strength concrete (Design strength of 600 kg/cm^2 and maximum of 800 kg/cm^2). Effective pre-stresses are 40 kg/cm^2, 80 kg/cm^2 and 100 kg/cm^2 for types A, B and C respectively. Typical drawings for pre-stressed concrete pile are shown in the following figure.



B	T	D	a	b	d	f	l	c	Weight (t/m)
500	80	340	40	125	250	30	10.0	5.0	0.37
600	100	400	40	125	290	35	12.0	5.5	0.57
700	110	480	40	125	350	35	14.0	6.1	0.76
800	120	560	40	125	400	35	16.0	6.6	0.98

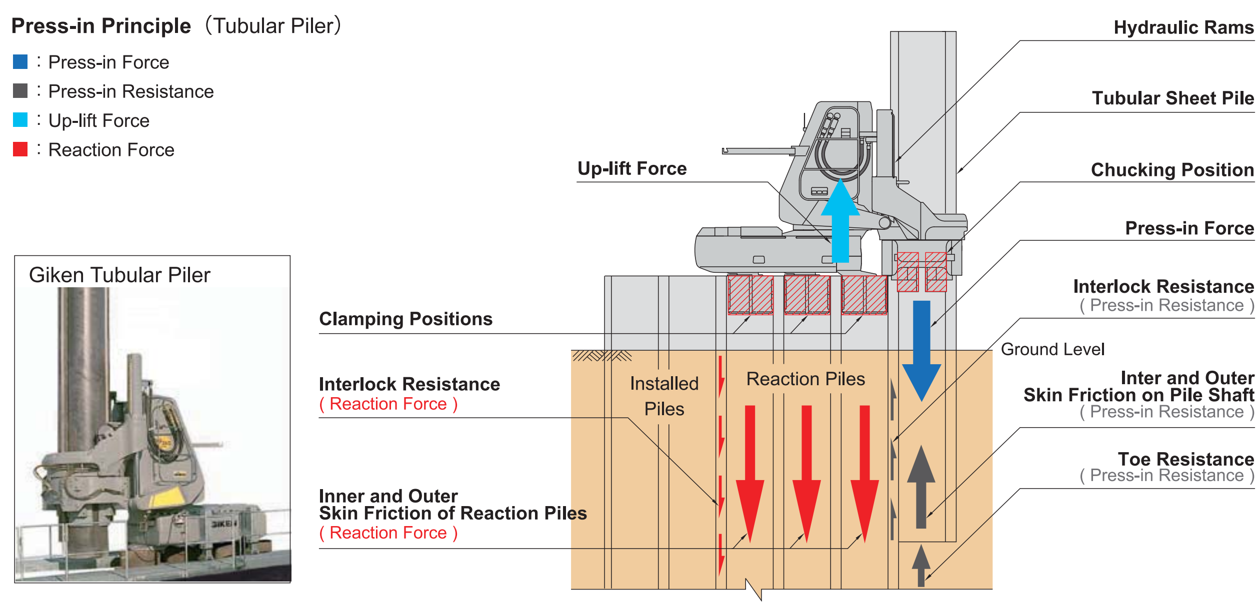


The pile is installed by a hydraulic jacking machine attached to a crawler crane with drilling by an auger inserted in the central void of the pile. The quality of piles is assured because by factory production. Noise and vibration can be minimized due to installation by hydraulic machine. However, equipment and materials to be used for the method are very heavy and firm temporary staging should be considered for safety purpose. Careful control is required to avoid damage of the pile head and toe. Work should be carried out in the following sequence;

1. Setting out and installation of ruler for pile installation.
2. Install the auger screw in the void of the pile.
3. Lifting pile and set in the designated position
4. Install the pile with augering and removing soil.
5. Additional pile is lifted and set in position and the joint welded..
6. Upon completion of piling, cement milk will be injected if the piles require bearing capacity.
7. Piles are connected to each other by welding the steel plates together.

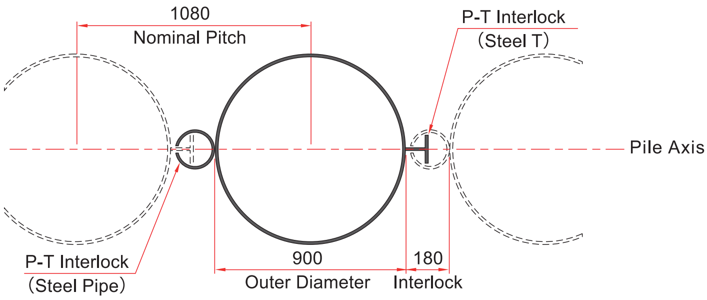
Pressed-in Steel Tubular Sheet Pile Wall (Giken Wall) (ϕ = 900 mm at 1080 mm centres)

The Giken Tubular Piler gains its reaction force by gripping onto three previously installed piles and then hydraulically jacks teh next prefabricated steel tubular sheet pile into ground (The Press-in Method). The Mechanism of the Press-in Method is illustrated below. Obvious advantages can be seen as there is no perceived vibration.



The system employed was designed to allow the operation of machines in areas with limited access to allow for perfect "top-down" construction. It consists of three machines working in unison: The Super Crush Tubular Piler, the Clamp Crane and the Pile Runner. The Piler self-moves to the next installation position without crane support. The Clamp Crane and the Pile Runner also utilize previously installed pile heads as their working platform (Non-staging System). Typical dimensions of steel tubular sheet piles and the machine layout of the Non-staging System are shown in the following figure.

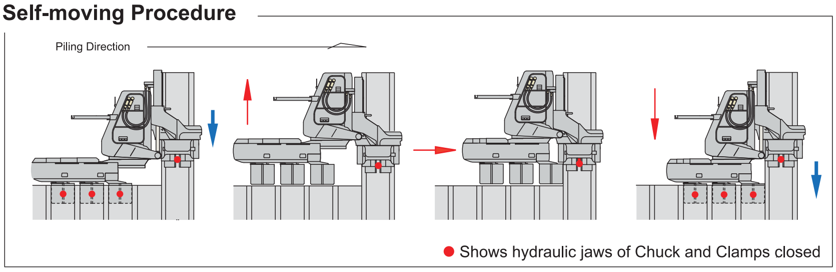
Press-in Principl

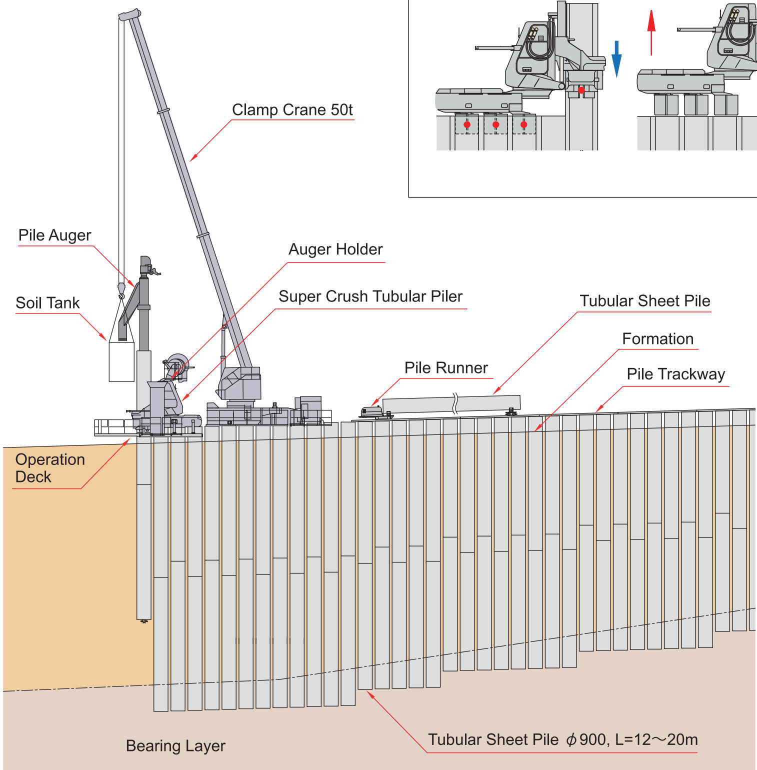


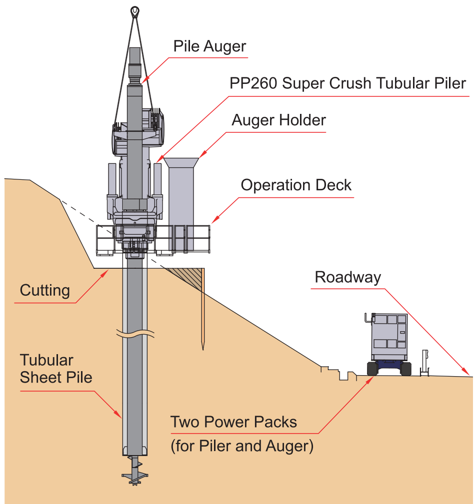
The Giken Wall as seen after excavation work.

Press-in Principl

Self-moving Procedure



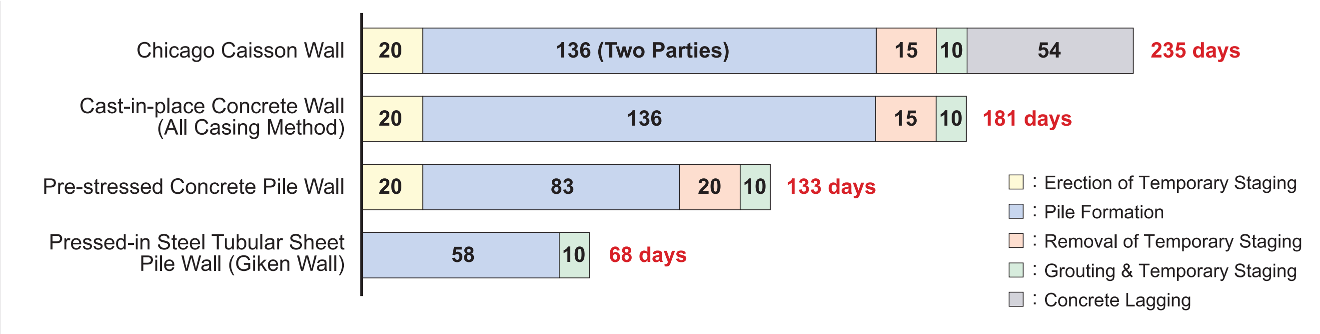




Study of the Construction Period

Construction periods were estimated for the four methods stated above. The estimated construction time is based on actual working days and no allowance for bad weather, holidays or any other days when work cannot be carried out has been made. Furthermore the time required for mobilization and assembling machines, pavement work and fixing decorated panels are assumed to be same for all methods and have not been counted in the construction period we estimated herein for comparison purposes. All methods except pressed-in steel tubular sheet pile wall (Giken Wall) require temporary staging for working and material storage platform. Although the temporary staging required for Chicago caisson may be lighter than the temporary staging for pre-stressed concrete pile wall and cast-in-place (all casing method) concrete wall methods, the same type of staging is assumed for all three methods considering that two (teams work) (parties are carried out) simultaneously for the Chicago caisson method. As the results of our estimation we found the following construction periods for each method.

Construction Schedule for Retaining Wall by Four Methods per 100m



It was obvious that construction period can be shorten remarkably using Giken Wall system as compared with other three methods.

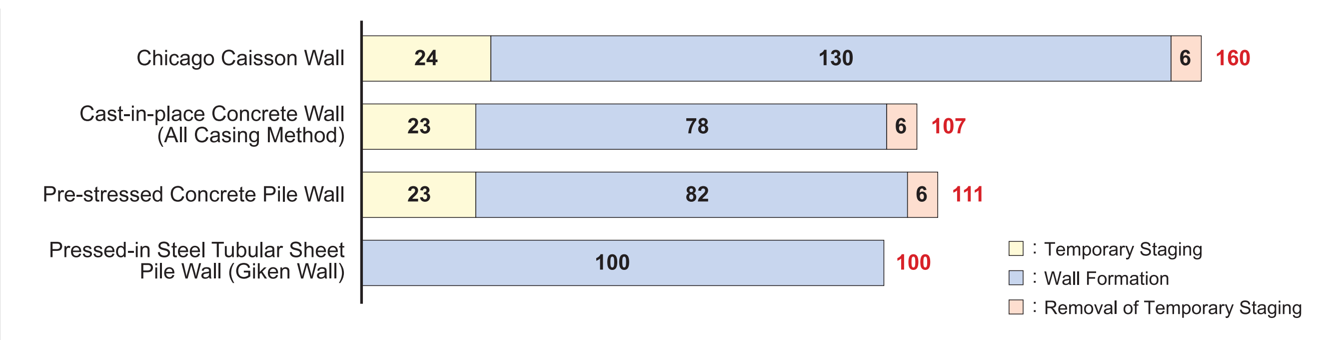
Study of Construction Cost

Construction cost was estimated based on the standard method of estimation, which is established by the Ministry of Land Infrastructure and Transport in Japan and based on the market prices of materials, manpower and equipments now prevailing in Japan. The costs are shown indexed in relation to a cost for pressed-in steel tubular sheet pile wall (Giken Wall) of 100. As the results of estimation we found the cost indices for Chicago caisson wall, cast-in-place concrete wall and pre-stressed concrete pile wall to be 160, 107 and 111. The Giken Wall is the most cost effective among other alternative methods. Considering indirect costs such as management and overheads, etc, the cost difference becomes greater due to the shorter construction period.

For comparison purposes the following costs were not considered for the estimation:

1. Mobilization and Demobilization
2. Preliminaries and overhead and profit etc (just direct cost only)
3. Assembling of machines and equipment
4. Transportation of Equipment and Materials
5. Excavation of front part of embankment after completion of pile wall formation
6. Subgrade and subbase and asphalt pavement
7. Decorated Panel Fixing
8. Other works such as drainage etc

Cost Indices for Four Methods



Life Cycle Assessment (LCA)

The environmental performance of structures over their whole life is becoming an increasingly important consideration for the construction industry. Clients, architects, engineers and others in the construction sector now rank environmental performance among the most important issues to be addressed by the industry.

In addition to the cost, time and quality this will be the most important aspect to evaluate construction methods or equipment in 21st century for sustainable development. Life cycle assessment studies need to be undertaken that consider a wide range of environmental burdens. In this evaluation the concept of embodied energy is used to allow the comparison of environmental impact for the four construction methods to be made. The figures of embodied energy intensities are scattered depending on the sources as shown in Table 2. Therefore embodied energy intensities for relevant construction materials are assumed as shown in Table 1 for comparative purpose. We calculated the embodied energy for production of construction material and equipment, for transportation of equipment and materials and for construction of retaining wall.

Table 1: Embodied Energy Intensity & Factor of CO_2 Emission used for Calculation

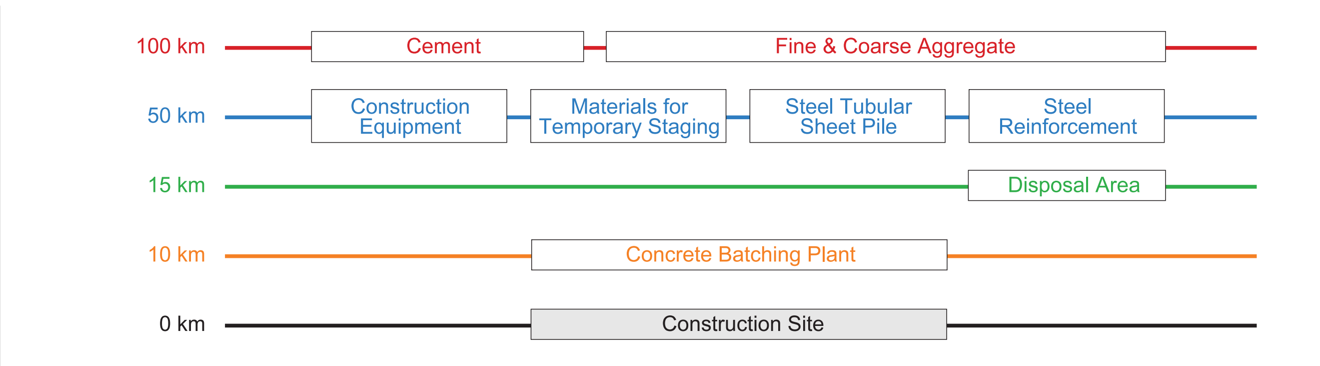
Materials	Embodied Energy Intensity (MJ/kg)
Steel, virgin	55
Steel, recycled	10
Concrete	2
Diesel	36
Plywood	18

Table 2: Comparison of Embodied Energy (MJ/kg) & Figures employed for study								
Name	Data from							Data employed for study
	Alcorn (25) *1	Buchanan(10)*1	FEMP (26) *1	Lawson*1	Germany*2	US*3	Japan*4	
Steel, recycled, section	8.9							10
Steel, recycled, wire rod	12.5							
Steel, virgin, General		32						
Steel, virgin, section		59	25.7 - 39.0	35				
Steel, rod		34.9				35		55
Steel, general		34.9						
Steel Pipes		56.9						
Basic Oxygen Steel, coated sheet				38				
Basic Oxygen Steel, stud				38				
Electric Arc Furnance Steel, reinforcing rod				10				
Cement	7.8	9						8
Concrete 30MPa	1.4	1.6	1.2 - 2.0	2		2		2
Concrete Precast			2					
Crude Oil					36.2		38.7	
Diesel					35.7		37.3	36
Natural Gas					31.7			

*1 : Data from the fourth year thesis by Joanna Glover, Department of Chemical Engineering University of Sydney
*2 : Data from the home page http://www.umweltbundesamt.de/uba-info-daten-e/daten-e/carbon-dioxide-emission.html
*3 : Data from the Forest Products Management Development Institute, University of Minnesota
*4 : Data from the report titled " Energy Consumption and Carbon Dioxide Emission, Intensity Based on the Input-Output Analysis prepared by Mr.Yoichi Moriguchi of National Institute for Environmental Studies, Emvironmental Agency of Japan & Mr. Keisuke Nansai of Grduate School of Energy Science, Kyoto University.

Distances to transport construction materials and equipment to the construction site are assumed for the study on life cycle assessment analysis as the following figure.

Distance to Construction Site for Construction Equipment & Materials to conduct the Life Cycle Assessment



Material Production

Fig.1 illustrates the material usage per 100 m length for each of the retaining wall structures. Chicago caisson wall uses over fourteen times the mass of material as pressed-in steel tubular sheet pile wall (Giken Wall). It is very clear that the Giken Wall is the most efficient in terms of material usage than any other methods. Temporary staging requires 557 tons of steel to secure working and storage space for all methods except the Giken Wall. The mass of material used was converted into embodied energy using the values of 55 MJ/kg (virgin steel), 10 MG/kg (recycled steel) and 2 MJ/kg for concrete. The embodied energy of the material used in each of the four methods is shown in Fig.2.

Fig.1 Material Use in Retaining Structure per 100m wall (ton)

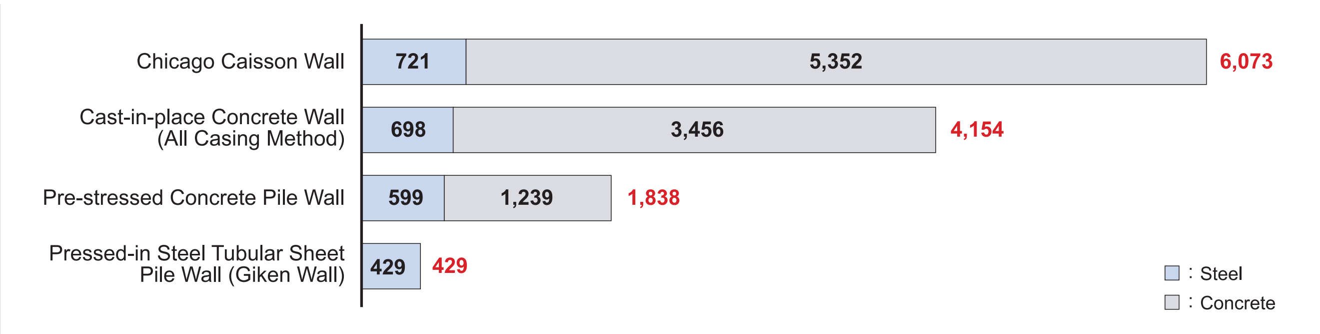
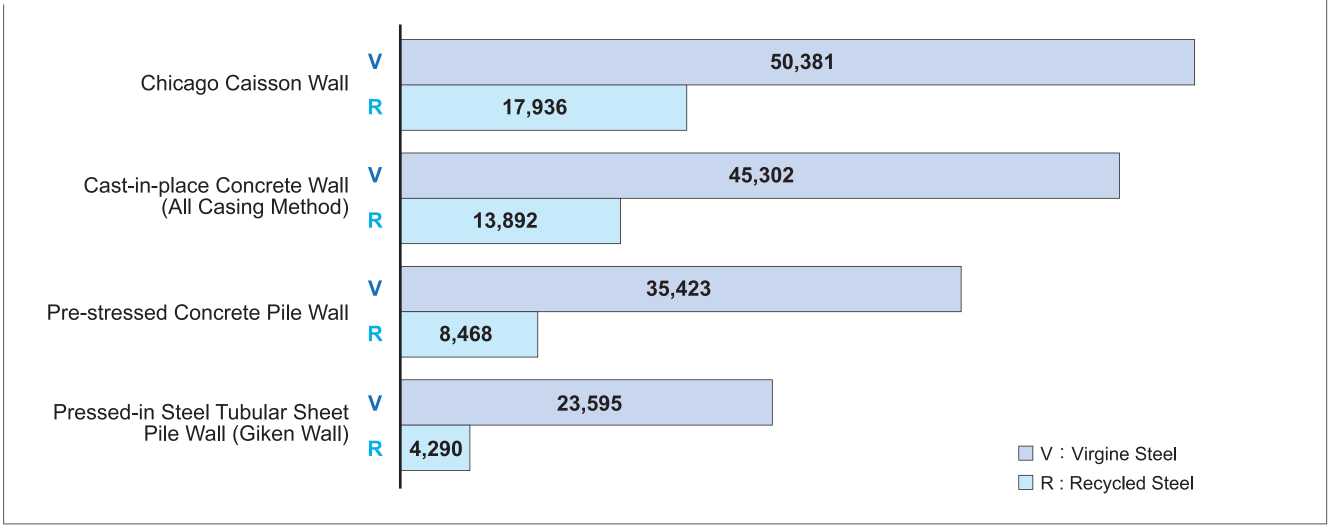


Fig.2 Environmental Impact Assessment (Material) GJ

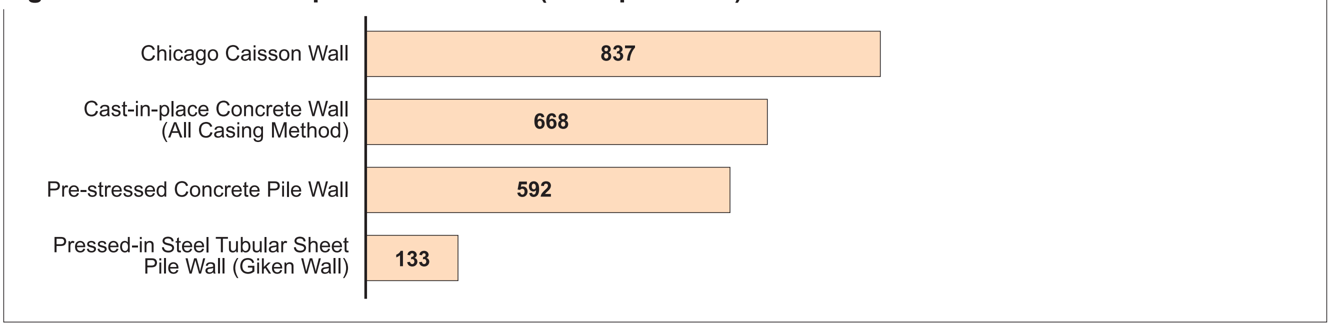


The Giken Wall requires 23,595 GJ per 100 m length of wall or 236 GJ per meter and proves the most efficient when only materials are considered. Details of the materials used and their environmental impact assessment are attached in Appendix 1.

Transportation

Using the figures 36 MJ/kg for diesel and assuming a delivery distance for steel of 50 km, for concrete of 10 km and for disposal of soil of 15 km per load, the energy used to transport the materials to site has been calculated for mobilization and demobilization of construction equipment and materials and for disposal of excavated soil. Details of the calculation of fuel consumption for transportation are attached in Appendix 2. The embodied energy required for the four methods is shown in Fig.3. Embodied energy for the Giken Wall is 133 GJ, while that for the other three methods are 5 or 6 times higher than the Giken Wall.

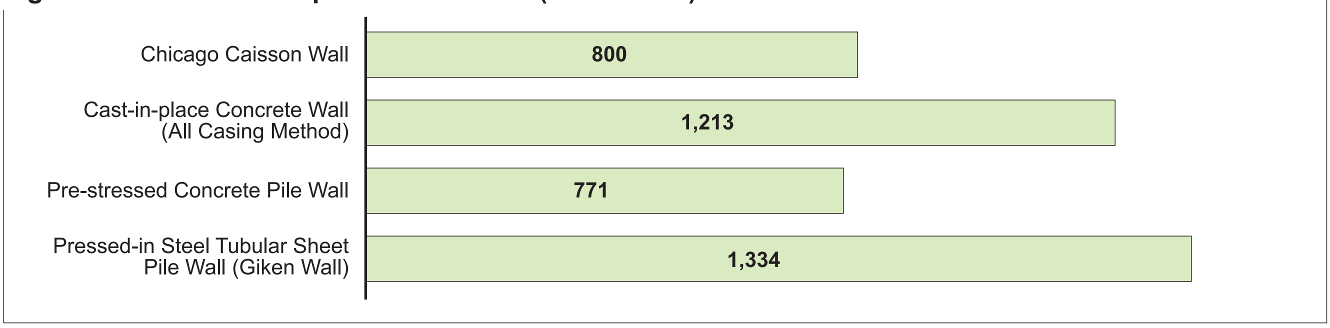
Fig.3 Environmental Impact Assessment (Transportation)



Installation

Evaluation of the energy levels associated with installation of the four methods was carried out by the fuel consumption required during installation of the wall structures. Details of fuel consumption for the four methods are shown in Appendix 3. The embodied energy for the four methods is shown in Fig.4. The Pre-stressed concrete pile wall is the most efficient when only installation is considered.

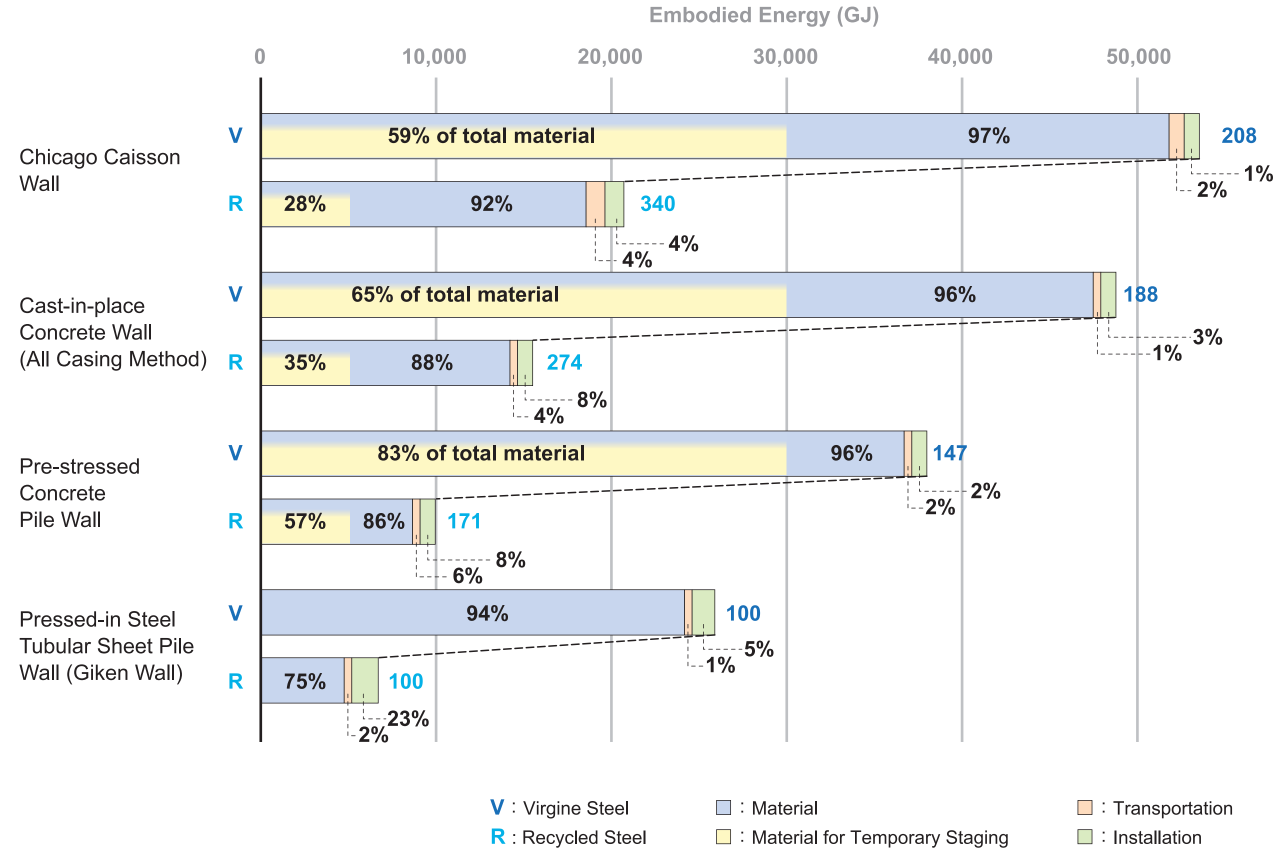
Fig.4 Environmental Impact Assessment (Installation)



Total Energy Used

Fig. 5 sums up the three assessed energy uses, and compares the total energy required to construct the retaining structure for the four different methods. It is apparent that the material embodied energy is most significant in all cases and occupies over 90% of total energy required when virgin steel is used. If recycled steel is used, significant energy reduction can be achieved. Taking the total energy of the Giken Wall to be 100, energy factors required for Chicago caisson wall, cast-in-place concrete wall and pre-stressed concrete pile wall are 208, 188 and 147 for virgin steel and 340, 274, and 171 for recycled steel respectively. Among the material embodied energy approximately over 60% of energy is derived from the steel required for temporary staging. In this comparison we did not consider the energy required removing and disposing of materials at the end of the design life, however, a significant amount of energy may need to be used in removing concrete and transporting and crushing old concrete before it can be reused.

Fig.5 Results of Environmental Impact Assessment



Conclusion

1. The pressed-in steel tubular sheet pile wall (Giken Wall) is the most effective way in terms of cost, time and embodied energy required due to eliminating of the huge temporary staging.
2. Significant reductions in embodied energy can be achieved if recycled steel is used for steel tubular sheet piles,the total embodied energy being about 250 GJ per meter wall length.
3. Steel sheet piles can be extracted relatively easily at the end of their design life and the site can be redeveloped more easily.
4. Although the difference in direct cost between the Giken Wall and two of the other types of wall, i.e., pre-stressed concrete pile wall and cast-in-place concrete wall, is samll, a significant reduction will be realised considering indirect cost since the construction period for the Giken Wall is much (more than 50%) shorter than for other methods.

Appendix 1

Details of Environmental Impact Assessment (1/8 - 8/8)

1/8

Environmental Impact Assessment by Embodied Energy
Chicago Caisson Wall using Virgin Steel

Item	Unit	Quantity	Embodied Energy		Remarks
			Factor (MJ/kg)	Amount (GJ)	
Material					
Steel, Sections for Temporary Staging	ton	557	55	30,635	
Liner Plate	ditto	5	55	275	
Caisson Concrete 25MPa	ton	4,488	2	8,976	55 m^3 x 34 Nos x 2.4 ton/m^3 = 4,488 ton
Caisson Steel Reinforcement	ton	141	55	7,755	
Grouting	ton	765	2	1,530	9 m^3 x 100 Nos x 2.4 ton/m^3 = 765 ton
Formwork (Lumber)	kg	1,840	12	22	
Lagging Concrete	ton	99	2	198	2.9 m^3 x 33 Nos x 2.4 ton/m^3 = 99 ton
Lagging Steel Reinforcement	ton	18	55	990	
Sub-Total				**50,381**	
Transportation					
for Temporary Staging	kg	8,458	36	304	10,315 liter x 0.82 = 8,458 kg
for Chicago Caisson	kg	10,096	36	533	18,040 liter x 0.82 = 14,793 kg
Sub-Total				**837**	
Installation					
for Temporary Staging	kg	4,595	36	165	5,603 liter x 0.82 = 4,595 kg
for Chicago Caisson	kg	29,096	36	635	21,513 liter x 0.82 = 17,641 kg
Sub-Total				**800**	
Total				**52,019**	

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Environmental Impact Assessment by Embodied Energy
Chicago Caisson Wall using Recycled Steel

Item	Unit	Quantity	Embodied Energy		Remarks
			Factor (MJ/kg)	Amount (GJ)	
Material					
Steel, Sections for Temporary Staging	ton	557	10	5,570	
Liner Plate	ditto	5	10	50	
Caisson Concrete 25MPa	ton	4,488	2	8,976	55 m^3 x 34 Nos x 2.4 ton/m^3 = 4,488 ton
Caisson Steel Reinforcement	ton	141	10	1,410	
Grouting	ton	765	2	1,530	9 m^3 x 100 Nos x 2.4 ton/m^3 = 765 ton
Formwork (Lumber)	kg	1,840	12	22	
Lagging Concrete	ton	99	2	198	2.9 m^3 x 33 Nos x 2.4 ton/m^3 = 99 ton
Lagging Steel Reinforcement	ton	18	10	180	
Sub-Total				**17,936**	
Transportation					
for Temporary Staging	kg	8,458	36	304	10,315 liter x 0.82 = 8,458 kg
for Chicago Caisson	kg	14,793	36	533	18,040 liter x 0.82 = 14,793 kg
Sub-Total				**837**	
Installation					
for Temporary Staging	kg	4,595	36	165	5,603 liter x 0.82 = 4,595 kg
for Chicago Caisson	kg	17,641	36	635	21,513 liter x 0.82 = 17,641 kg
Sub-Total				**800**	
Total				**19,574**	

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Environmental Impact Assessment by Embodied Energy
Cast-in-place Concrete Wall (ϕ = 1000 mm x 17 m) using Virgin Steel

Item	Unit	Quantity	Embodied Energy		Remarks
			Factor (MJ/kg)	Amount (GJ)	
Material					
Steel, Sections for Temporary Staging	ton	557	55	30,635	
Concrete 30MPa	ton	3,456	2	6,912	14.4 m^3/No x 100 Nos x 2.4 ton/m^3 = 3,456 ton
Steel Reinforcement	ton	141	55	7,755	
Sub-Total				**45,302**	
Transportation					
for Temporary Staging	kg	8,458	36	304	10,315 liter x 0.82 = 8,458 kg
for Cast-in-place Concrete Pile	kg	10,096	36	363	12,312 liter x 0.82 = 10,096 kg
Sub-Total				**668**	
Installation					
for Temporary Staging	kg	4,595	36	165	
for Cast-in-place Concrete Pile	kg	29,096	36	1,047	35,483 liter x 0.82 = 29,096 kg
Sub-Total				**1,213**	
Total				**47,183**	

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Environmental Impact Assessment by Embodied Energy
Cast-in-place Concrete Wall (ϕ = 1000 mm x 17 m) using Recycled Steel

Item	Unit	Quantity	Embodied Energy		Remarks
			Factor (MJ/kg)	Amount (GJ)	
Material					
Steel, Sections for Temporary Staging	ton	557	10	5,570	
Concrete 30MPa	ton	3,456	2	6,912	14.4 m^3/No x 100 Nos x 2.4 ton/m^3 = 3,456 ton
Steel Reinforcement	ton	141	10	1,410	
Sub-Total				**13,892**	
Transportation					
for Temporary Staging	kg	8,458	36	304	10,315 liter x 0.82 = 8,458 kg
for Cast-in-place Concrete Pile	kg	10,096	36	363	12,312 liter x 0.82 = 10,096 kg
Sub-Total				**668**	
Installation					
for Temporary Staging	kg	4,595	36	165	
for Cast-in-place Concrete Pile	kg	29,096	36	1,047	35,483 liter x 0.82 = 29,096 kg
Sub-Total				**1,213**	
Total				**15,773**	

5/8

Environmental Impact Assessment by Embodied Energy Pre-stressed Concrete Pile Wall using Virgin Steel					
Item	Unit	Quantity	Embodied Energy		Remarks
			Factor (MJ/kg)	Amount (GJ)	
Material					
Steel, Sections for Temporary Staging	ton	557	55	30,635	
Pre-cast Concrete	ton	1,176	2	2,352	0.1441 m^2 x 17 m x 2.4 ton/m^3 x 200 Nos = 1,176 ton
PC Strand	ton	42	55	2,310	$(0.01)^2 x \pi /4x17mx7.8t/m^3x20Nos/Nox200Nos=42$ ton
Water Proofing Mortar	ton	63	2	126	25 m^3 x 2.5 ton/m^3
Sub-Total				**35,423**	
Transportation					
for Temporary Staging	kg	8,458	36	304	10,315 liter x 0.82 = 8,458 kg
for Pre-stressed Concrete Pile	kg	7,975	36	287	9,725 liter x 0.82 = 7,975 kg
Sub-Total				**592**	
Installation					
for Temporary Staging	kg	4,575	36	1,334	
for Pre-stressed Concrete Pile	kg	16,845	36	1,334	20,542 liter x 0.82 = 16,845 kg
Sub-Total				**1,334**	
Total				**25,062**	

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Environmental Impact Assessment by Embodied Energy Pre-stressed Concrete Pile Wall using Recycled Steel					
Item	Unit	Quantity	Embodied Energy		Remarks
			Factor (MJ/kg)	Amount (GJ)	
Material					
Steel, Sections for Temporary Staging	ton	557	10	5,570	
Pre-cast Concrete	ton	1,176	2	2,352	0.1441 m^2 x 17 m x 2.4 ton/m^3 x 200 Nos = 1,176 ton
PC Strand	ton	42	10	420	$(0.01)^2 x \pi /4x17mx7.8t/m^3x20Nos/Nox200Nos=42$ ton
Water Proofing Mortar	ton	63	2	126	25 m^3 x 2.5 ton/m^3
Sub-Total				**8,468**	
Transportation					
for Temporary Staging	kg	8,458	36	304	10,315 liter x 0.82 = 8,458 kg
for Pre-stressed Concrete Pile	kg	7,975	36	287	9,725 liter x 0.82 = 7,975 kg
Sub-Total				**592**	
Installation					
for Temporary Staging	kg	4,575	36	165	
for Pre-stressed Concrete Pile	kg	16,845	36	606	20,542 liter x 0.82 = 16,845 kg
Sub-Total				**771**	
Total				**9,831**	

7/8

Environmental Impact Assessment by Embodied Energy Pressed-in Steel Tubular Sheet Pile Wall (ϕ= 900 mm x 17 m) using Virgin Steel					
Item	Unit	Quantity	Embodied Energy		Remarks
			Factor (MJ/kg)	Amount (GJ)	
Equipment					
Steel Tubular Sheet Pile	ton	429	55	23,595	
Sub-Total				**23,595**	
Equipment					
for Steel Tubular Sheet Pile	kg	3,682	36	133	4,491 liter x 0.82 = 3,683 kg
Sub-Total				**133**	
Material					
for Steel Tubular Sheet Pile	kg	37,059	36	1,334	45,194 liter x 0.82 = 37,059 kg
Sub-Total				**1,334**	
Total				**25,062**	

8/8

Environmental Impact Assessment by Embodied Energy Pressed-in Steel Tubular Sheet Pile Wall (ϕ= 900 mm x 17 m) using Recycled Steel					
Item	Unit	Quantity	Embodied Energy		Remarks
			Factor (MJ/kg)	Amount (GJ)	
Equipment					
Steel Tubular Sheet Pile	ton	429	10	4,290	
Sub-Total				**4,290**	
Equipment					
for Steel Tubular Sheet Pile	kg	3,682	36	133	4,491 liter x 0.82 = 3,683 kg
Sub-Total				**133**	
Material					
for Steel Tubular Sheet Pile	kg	37,059	36	1,334	45,194 liter x 0.82 = 37,059 kg
Sub-Total				**1,334**	
Total				**5,757**	

Appendix 2

Details of Fuel Consumption for Transportation of Construction Materials and Equipment (1/5 - 5/5)

1/5

Fuel Consumption for Transportation of Equipment & Material (Mobilization & Demobilization) Temporary Staging								
Item	Specification	Transported by	ps	Nos / Trip	Number of Trips	Cm/60= (β.L+α) / 60 *	Liter /ps.h	Fuel Consumption (Liter)
			(1)	(2)	(3)	(4)	(5)	(1)*(2)*(3)*(4)*(5)
Equipment								
Crawler Crane	50 ton	32 ton Semi Trailer	320	2	2	6.7	0.056	480
		11 ton Truck	311	3	2	6.7	0.04	500
Generator		11 ton Truck	311	1	2	6.7	0.04	167
Material								
Steel Material		11 ton Truck	311	55	2	6.7	0.04	9,168
Total								**10,315**

2/5

Fuel Consumption for Transportation of Equipment & Material (Mobilization & Demobilization)
Chicago Caisson Wall (ϕ = 2000 mm x 17 m 34Nos, w 500 x 1000 x 6.0 m - 33 Nos)

Item	Specification	Transported by	ps (1)	Nos / Trip (2)	Number of Trips (3)	Cm/60= (β.L+α) / 60 * (4)	Liter /ps.h (5)	Fuel Consumption (Liter) (1)*(2)*(3)*(4)*(5)
Equipment								
Back Hoe	0.6 m^3, 126 ps,18.6 ton	20 ton Semi Trailer	320	1	2	6.7	0.056	240
Air Compressor	5.0 m^3 /min, 50 ps, 1.0 ton	11 ton Truck	311	1	2	6.7	0.04	167
Grout Pump	37-100 liter/min, 7.8 kW, 0.36 ton							
Grout Mixer	200 liter x 2-2.2 kW, 0.23 ton							
Concrete Bucket	0.6 m^3- 0.5 ton							
Liner Plate		11 ton Truck	311	34	2	6.7	0.04	5,668
Material								
Concrete	1,870	Mixer Truck (4.5 m^3/290 ps)	290	34	2	1.1	0.044	954
Concrete by Pump	90 - 110 m^3/h, 270 ps	Conrete Pumping Car	270	34	2	4.7	0.062	5,350
Concrete by Bucket	10 ton	Truck Crane	230	5	2	4.7	0.037	400
Steel reinforcement	141.2 ton	11 ton Truck	311	34	2	6.7	0.04	5,668
Total								**18,040**

3/5

Fuel Consumption for Transportation of Equipment & Material (Mobilization & Demobilization)
Cast-in-place Concrete Wall (ϕ = 1000 mm x 17 m - 100 Nos)

Item	Specification	Transported by	ps (1)	Nos / Trip (2)	Number of Trips (3)	Cm/60= (β.L+α) / 60 * (4)	Liter /ps.h (5)	Fuel Consumption (Liter) (1)*(2)*(3)*(4)*(5)
Equipment								
Augering Machine	392 ps, 80 ton	32 ton Semi-trailer	320	3	2	6.7	0.056	720
Crawler Crane	50 ton - 48.8 ton	32 ton Semi-trailer	320	2	2	6.7	0.056	480
		11 ton Truck	311	2	2	6.7	0.04	333
Casing Tube	ϕ=1000 x 6 m, 4.4 ton	11 ton Truck	311	1	2	6.7	0.04	167
Hammer Grab	ϕ=1000 mm, 1.7 ton	11 ton Truck	311	34	2	6.7	0.04	167
First Tube	ϕ=1000 mm, 1.6 ton							
Hammer Crown	less than 1200, 0.1 ton							
Casing Tube	ϕ=1000 x 5 m, 3.7 ton							
Material								
Concrete	4.5 m^3, 290 ps	Mixer Truck	290	4	200	1.1	0.044	11,229
Steel Reinforcement	141 ton	11 ton Truck	311	1	13	6.7	0.04	1,084
Total								**12,312**

Fuel Consumption for Transportation of Equipment & Material (Mobilization & Demobilization)
Pre-stressed Concrete Pile Wall (□500 x 500 x 17.0 m - 200 Nos)

Item	Specification	Transported by	ps	Nos / Trip	Number of Trips	Cm/60= (β.L+α) / 60 *	Liter /ps.h	Fuel Consumption (Liter)
			(1)	(2)	(3)	(4)	(5)	(1)*(2)*(3)*(4)*(5)
Equipment								
Hydraulic Installation Machine	45 kW	32 ton Semi Trailer	320	4	2	6.7	0.056	961
Crawler Crane	50 ton	ditto	320	2	2	6.7	0.056	480
Backhoe	0.4 m^3	15 ton Tailer	320	1	2	6.7	0.056	240
Material								
Pre-stressed Concrete Pile	0.37 ton/m	20 ton Semi Trailer	320	67	1	6.7	0.056	8,044
Total								**9,725**

5/5

Fuel Consumption for Transportation of Equipment & Material (Mobilization & Demobilization)
Pressed-in Steel Tubular Sheet Pile Wall (ϕ= 900 mm, 1080 mm in Space)

Item	Specification	Transported by	ps	Nos / Trip	Number of Trips	Cm/60= (β.L+α) / 60 *	Liter /ps.h	Fuel Consumption (Liter)
			(1)	(2)	(3)	(4)	(5)	(1)*(2)*(3)*(4)*(5)
Equipment								
Crush Piler & Accessories	Press-in Force 2,600 kN	32 ton Trailer	320	2	2	6.7	0.056	480
Clamp Crane & Accessories	Lifting Capacity 50 ton	32 ton Trailer	320	2	2	6.7	0.056	480
Clamp Crane (Boom)		11 ton Truck	311	1	2	6.7	0.04	167
Engine Unit EU200 & Accessories	Rated Output 147 kW (200 ps)	11 ton Truck	311	2	2	6.7	0.04	333
Pile Auger	ϕ=900 mm	11 ton Truck	311	1	2	6.7	0.04	167
Weight for Clamp Crane	25 ton	32 ton Trailer	320	1	2	6.7	0.056	240
Material								
Steel Tubular Sheet Pile	485.4 ton	11 ton Truck	311	45	1	6.7	0.04	3,751
Total								**4,491**

* Cm: Cycle time (minutes).
Time required per trip.

β: Time factor required per km distance (minutes).
5.6 70% of route is urban area and congested.
5.1 30~70% of route is urban area and congested.
4.6 Less than 30% of route is urban and congested.

L: Distance from origin to construction site or vise versa (km).

α: Loading & unloading time per trip (minutes).

Details of Fuel Consumption for Installation (1/5 - 5/5)

1/5

Fuel Consumption for Installation and Removal
Temporary Staging

Item	Specification	ps	Liter/ps.h	Hours/day	Working days	Fuel Consumption (Liter)
		(1)	(2)	(3)	(4)	(1)*(2)*(3)*(4)
Erection						
Crawler Crane	50 ton, 139 ps, 47 ton	139	0.07	8.0	20	1,557
Generator	200 KVA, 259 ps, 3.67 ton	259	0.127	2.5	20	1,645
Removal						
Crawler Crane	50 ton, 139 ps, 47 ton	139	0.07	8.0	15	1,168
Generator	200 KVA, 259 ps, 3.67 ton	259	0.127	2.5	15	1,233
Total						**5,603**

2/5

Fuel Consumption for Installation
Chicago Caisson Wall (ϕ = 2000 mm, 3000 mm in space - 34 Nos)

Item	Specification	ps	Liter/ps.h	Hours/day	Working days	Fuel Consumption (Liter)
		(1)	(2)	(3)	(4)	(1)*(2)*(3)*(4)
Back Hoe	0.6 m^3, 126 ps, 18.6 ton	126	0.138	5.6	8.9	867
Dump Truck	10 ton	335	0.04	7.0	128.2	12,025
Concrete Pump Car	90-110 m^3/h	270	0.062	2.4	34.0	1,366
Air Compressor	5.0 m^3/min, 50 ps, 1.0 ton	50	0.139	5.3	15.0	553
Truck Crane	5 ton	160	0.037	3.9	272.0	6,280
	10 ton	240	0.037	2.8	5.0	124
	20 ton	240	0.037	2.8	12.0	298
Total						**21,513**

3/5

Fuel Consumption for Installation
Cast-in-place Concrete Wall (ϕ = 1000 mm x 17 m - 100 Nos)

Item	Specification	ps	Liter/ps.h	Hours/day	Working days	Fuel Consumption (Liter)
		(1)	(2)	(3)	(4)	(1)*(2)*(3)*(4)
Augering Machine	392 ps, 80 ton	166	0.135	6.5	136	19,810
Crawler Crane	50 ton - 48.8 ton	156	0.07	5.5	136	8,168
Dump Truck	10 ton	335	0.04	7.0	80	7,504
Total						**35,483**

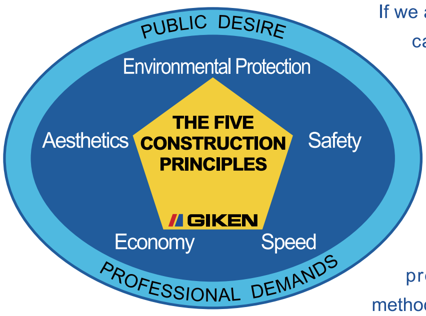
4/5

Fuel Consumption for Installation Pre-stressed Concrete Pile Wall (□ 500 x 500 x 17.0 m - 200 Nos)						
Item	Specification	ps	Liter/ps.h	Hours/day	Working days	Fuel Consumption (Liter)
		(1)	(2)	(3)	(4)	(1)*(2)*(3)*(4)
Hydraulic Installation Machine	45 kW	124	0.135	6.2	83	8,614
Crawler Crane	50 ton	156	0.07	5.6	83	5,076
Backhoe	0.4 m^3	86	0.138	2.1	83	2,069
Dump Truck	10 ton	335	0.04	7.0	51	4,784
Total						**20,542**

5/5

Fuel Consumption for Installation Pressed-in Steel Tubular Sheet Pile Wall (ϕ = 900 mm, 1080 mm in Space)						
Item	Specification	ps	Liter/ps.h	Hours/day	Working days	Fuel Consumption (Liter)
		(1)	(2)	(3)	(4)	(1)*(2)*(3)*(4)
Crush Piler (Engine Unit)	Rated Output 147 kW (200 ps)	147	0.271	6.3	58	14,556
Truck Crane	80 ton	147	0.271	6.3	58	14,556
Clamp Crane	Lifting Capacity 50 ton	96	0.279	6.3	58	9,787
Pile Runner	Rated Output 5.1 kW (7 ps)	5.1	0.418	6.3	58	779
Welding Machine	with 250A engine	12	0.231	6.3	58	1,013
Dump Truck	10 ton	335	0.04	7	48	4,502
Total						**45,194**

THE FIVE CONSTRUCTION PRINCIPLES



If we analyse all the parties involved in any construction work, we can categorize them into three main groups: the client, the contractor and the general public. The ideal situation is when all three parties are in agreement and satisfied with the successful outcome of the construction work. Problems arise when one of the parties becomes a victim of imbalance in this relationship. The conventional construction methods based upon principles that "more is paid for less efficient work" are no longer appropriate to present-day society. Universally acceptable construction methods must embody the Five Construction Principles.

Environmental Protection	Construction work should be environmentally friendly and free from pollution.
Safety	Construction work has to be carried out in safety and comfort with a method implementing the highest safety criteria.
Speed	Construction work should be completed in the shortest possible period of time.
Economy	Construction work must be done rationally with an inventive mind to overcome all constraints at the lowest cost.
Aesthetics	Construction work must proceed smoothly and the finished product should portray cultural and artistic flavour.

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