

1. Overview

1 Overview of Corrugated Steel Plate

Corrugated Steel Plate(CSP) structure is a structure assembled with corrugated steel plates, whose thickness is from 3.2mm to 8.0mm to increase the rigidity of structure significantly. In general, 150mm× 50mm or 400mm× 150mm profiles are available and its section modulus is 10 to 30 times more than non-corrugated steel plate. It is a product made of virgin steel plate without welding. Multi Plate profile is 150mm× 50mm and it is ideal for structure whose span is from 3m to 10m. Meanwhile Bridge Plate profile is 400mm x 150mm and ideal for structure whose span is from 3m to 28m and especially for box-type structure, which is perfect for waterflow, span size is available from 3m to 15m. Structures with longer span over 16m is equipped with reinforced system. With this method, the span can increase up to maximum 28m.

This CSP structure is already popular in Korea and especially in US, CSP structure and CS pipes took over 40% of in the drainage system market. In the late 1960s of US, CSP structures have been drastically increased in the field of bridge construction. Below are the reasons.

- Solving the problem that upper plates of the bridge is frozen.
- Upper plate of bridge showing no sign of decrepit.
- Allows construction of structure without hindering traffics on site.
- Assemblability on construction site
- Fast design and construction
- Environmentally friendly.
- Economical.



As mentioned above, CSP structure is easily constructed by assembling plates with bolt and nut, which saves construction time and cost. Since the main material of the structure is steel, it is recyclable after dismantling the structure, so it is environmentally friendly. Not only that, CSP structure is elastic and engineeredly soil-steel structure unlike reinforced concrete structure is rigid. The structure becomes elastic as the pressure such as automobiles, dirt, structure itself is given. And the pressure is dispersed to nearby soil to mitigate the load on the structure. Because of this engineered aspects, elastic soil-steel structure needs a lot of care compared to rigid reinforced concrete structure during the construction.

CSP structure is mainly used in highways, underpass, drainage culverts and other structure like bridge, temporary structures, ecological tunnels, etc. Thanks to CSP's assemblability, fast and economical construction and environmental-friendly, CSP structure is becoming popular.

2 History of C•S•P structure

CSP structure or Corrugated Multi Plate structure was invented by American engineer, James H. Watson, while he got the idea from wrapping corrugated cardboard around his drug bottle and eventually to use it as a drainage system. After that, Watson told the idea to his engineer friend, E. Stanley Simpson in Crawfordsville and started to make a corrugated metal pipe.

They made the registration of patentship in 1886, and is still used as a Corrugated Multi Plate drainage structure. CSP structure that needs bolt and nut assembly was first introduced in 1931. As the highway construction started in the 50s, CSP has been improved with bigger corrugation and used for waterways and alternative tunnels. In the beginning, it was used as a pipe-type small structure. From 1960s to 1980s, thanks to the AISI and NCSA's financial support, it resulted in a lot of researches and results. Section has been various and the panel size bigger. Even until today, A lot of efforts are being put into the research in order to make sections bigger.

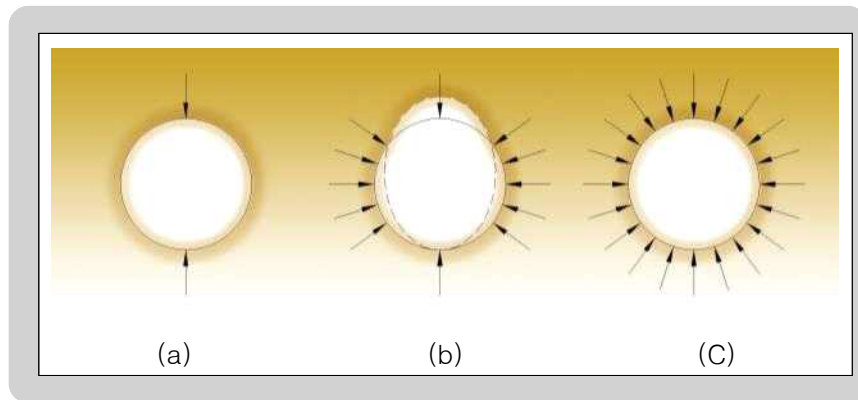
From 1934, Canadian company, Armtec has been leading the industry by producing Multi Plate and Super-Span for civil engineering. Especially they introduced Bridge Plate, which is economical and durable to meet customers' need in the market. Since this product has been improved by increasing profile size, this product is getting popular replacing reinforced concrete structures. The N.America's cases show that CSP structure will be gradually substituting concrete structures and be available with various section type, bigger size and various application.

3 CSPs Dynamic principles.

3.1 Dynamic properties.

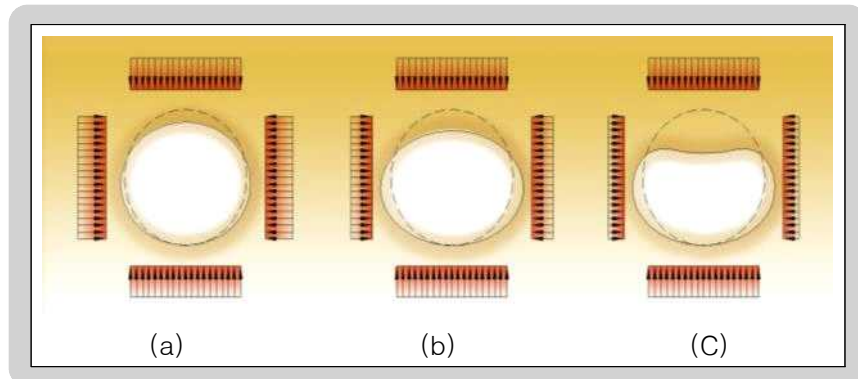
Corrugated structural plate thickness is from 3.2mm to 8.0mm and the rigidity is increased by giving corrugation. This has soil-steel compound structure system resisting against outer pressure, which is normally explainable by the ring compression theory by(White & Layer(1960)). Compression ring theory is depicted in the picture 1.1.

(a) in the picture 1.1 shows the structure is pressured by vertical soil pressure. (b) shows that the vertical direction of the diameter is diminished and the horizontal way of the diameter expanded. And the side soil contracts and resistant passive earth pressure occurs. (c) shows it eventually brings regular pressures to the structure. Since the CSP structure reacts like this ring compression theory, bending moment is inhibited and the movement is controlled by the latitudinal pressure.



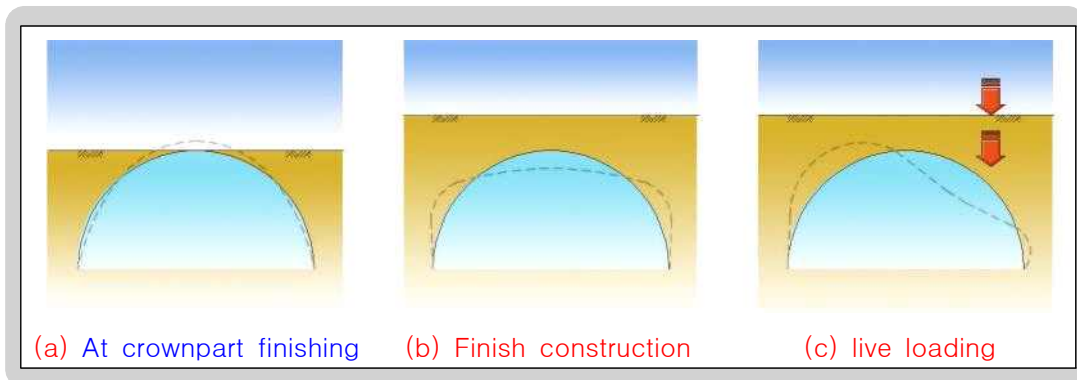
picture 1.1 Earth pressure distribution according to the ring compression theory.

Like above, Corrugated Steel Plate moves by the interaction of ground-structure, therefore required backfilling resources and assurance is pivotal. If assurance is not made by abundant backfilling resources following the regulations, the structure may not move by the compression ring theory, or deform into the side like in picture 1,2b or the partial deformation in picture 1,2 c.



picture 1.2 deformation of Corrugated Multi Plate

But, structure with longer span can, during or after the construction, have bending moment like in picture 1,3 which is a major concern in structure design. Therefore the consideration of bending moment in structure design is required. In CHBDC(2001), engineers consider bending moment for safety during the construction.



picture 1.3 Bending moment at each construction stage

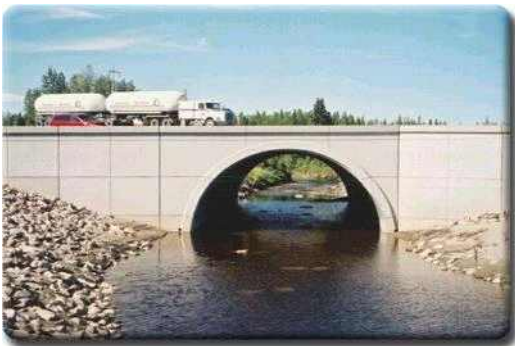
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CSP Applications

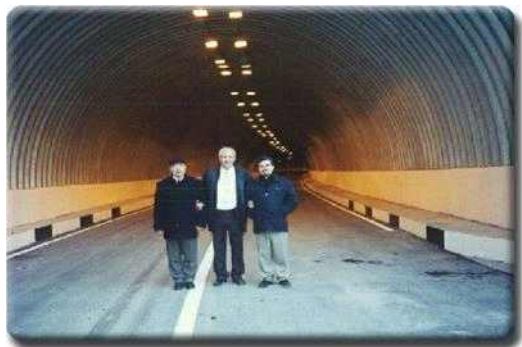
Small or medium bridges



Culvert and tunnels



Open-cut tunnel, eco-corridor)



etc



Chapter 2. construction

corrugated steel plate structure is an important structure need in interaction of the structure and the backfilling of dirt. Therefore, By using adequate backfilling materials, assure by the regulations and make sure the interaction is at its utmost by constructing the soil and the structure properly. But before interacting, backfilling process or minimum soil layer height is assured steel structure ' wall may be destructed by the upper pressure to the structure's surrounding. So, not only design but construction process is pivotal to follow the regulations strictly.

1 construction notice

1.1 Meeting prior to construction.

meeting prior to the construction require deputy of the owner, engineer, soil specialist, material specialist, contractor, construction firm, and concrete construction deputy shall attend and the work place steel plate manufacturer's inspectors also.

Purpose of the meeting is to confirm to the plate manufacturer's requirements and other opinions shared for agreement in various aspects of the construction process. The memo of the meeting shall be written by the deputy of the owner and provide it to the rest of the members.

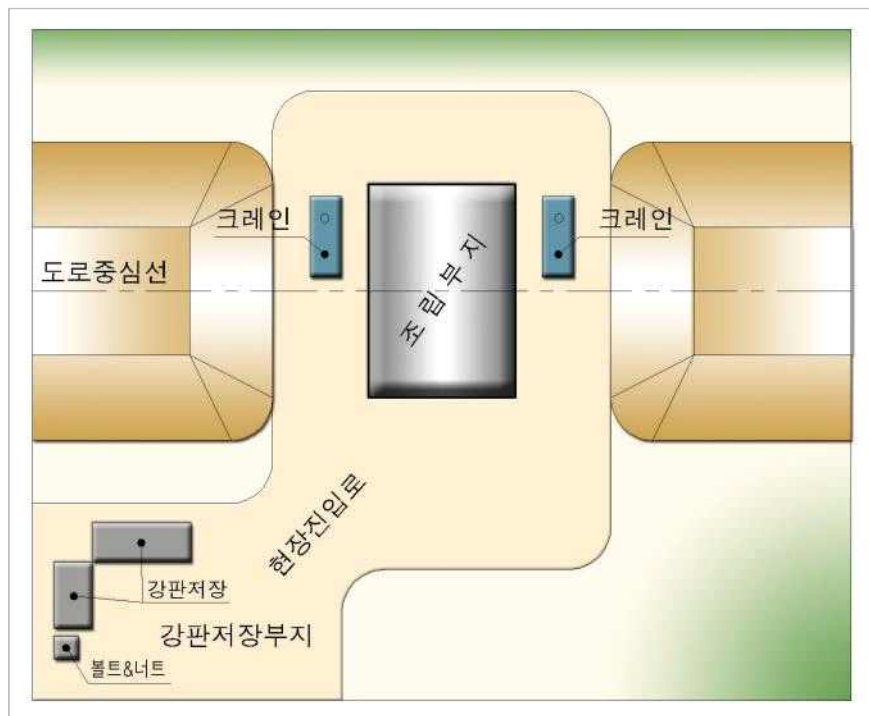
1.2 Construction preparation on site.

Administrator shall make plans for the working people, materials and tools, working schedules, and sequence of steel plate construction and structure change estimation. Also set up plots for steel plate materials and transportation of such to the working place. construction plans and measuring plans shall be admitted by the chief engineer and the construction inspector and construct upon the contents of construction and design blueprint.

After the admission, checking Elevation of core areas of construction location by measuring is to be made before ground steel plate construction, and make a ground plot for keeping, and entering of corrugated plate's materials near the construction location. Corrugated plate construction is processed from higher to lower ground and like the picture 4.1, it is adequate to place roads to transport materials in the lower side of the land. Especially when fixing a structure to a waterway, measures in turning the waterway shall be made. When constructing partially, locomotion of materials shall be possible as close as possible to the construction location. In highway places, entrance and steel plate storage must be set before construction.



picture 4.1 basic steel plate construction



picture 4.2 construction plot by highway

1.3 Examination of materials.

Domestic standards for corrugated steel plates are designated in KS D 3590, yet it is the same as Japan's JIS regulations, being a bit different from the FIXON's corrugated steel plates. Especially, 4.5m is the maximum adjustable surface size and round and pipe arch form are the only ones available according to the KS. There is a lot of difference of sizes and adjustable surface forms in domestic corrugated steel plates. But basically steel plate's size's error range and the standards of iron coating can be adjusted to the ones in KS, making not much of a problem in following KS standards when counting materials.

When steel plates are entered to the work place, check how many plates are there by sizes, and bolts and nuts. In case of arch form structure, check the fixed channel's size and length for connecting basis of concrete and the steel plate. After counting, check any harm to it, and if there are some harms found by the transportation process, cancel the entering immediately and carry in only when remanufactured and renewed. Corrugated plates with too much damage shall be checked and never should be carried in, but little bendings in the corner side is usable under the fact that it does not effect structure wise.

Steel plate is used as a long term structure of the highways' duration span, making it examine the substances and growth, strength and yield force. Also, it shall be carried in the form of iron coating (hot rolled galvanized coil, KS D 3506) having more than 900g/m² of both sided coating standards of steel plate according to KS standards. examination of checking Iron plating amount is to be made with the same treated materials of the working place, and may use magnetic piece of gage for it is a test to be checked at the working places. When counting the iron coatings by using pieces of gage, ratio of iron shall be 6.1g/kg. If the Amount of iron coating is too small, Cancel the entrance and immediately report the reasons and examine by recoating. Even after entrance is admitted, and harms occurred by lack of caution at the working place shall be treated by cleaning the harmed surface, and a iron coating spray.

Bolt and nut should basically have electric iron coatings sufficient enough for the iron remainings to smoothen the screw line. Bolt is differed in 2 ways by its length in amount of steel plates piling up. Fixed channel and anchor bolts are the subsidizing materials and these all should follow the standards of manufacture.

2

Construction procedures of CSP structure

Corrugated Multi Plate construction differs from open surfaces like half circle, high arch, low arch, box form etc and closed surfaces like round, pipe arch, underpass, horizontal oval forms and closed surfaces follow quick construction. The following is the construction sequence of open surface.

fundamental design



point surface fixation



construction I



construction II



side wall



backfilling I



backfilling II



backfilling III



backfilling (prior) I



backfilling (prior) II



assurance



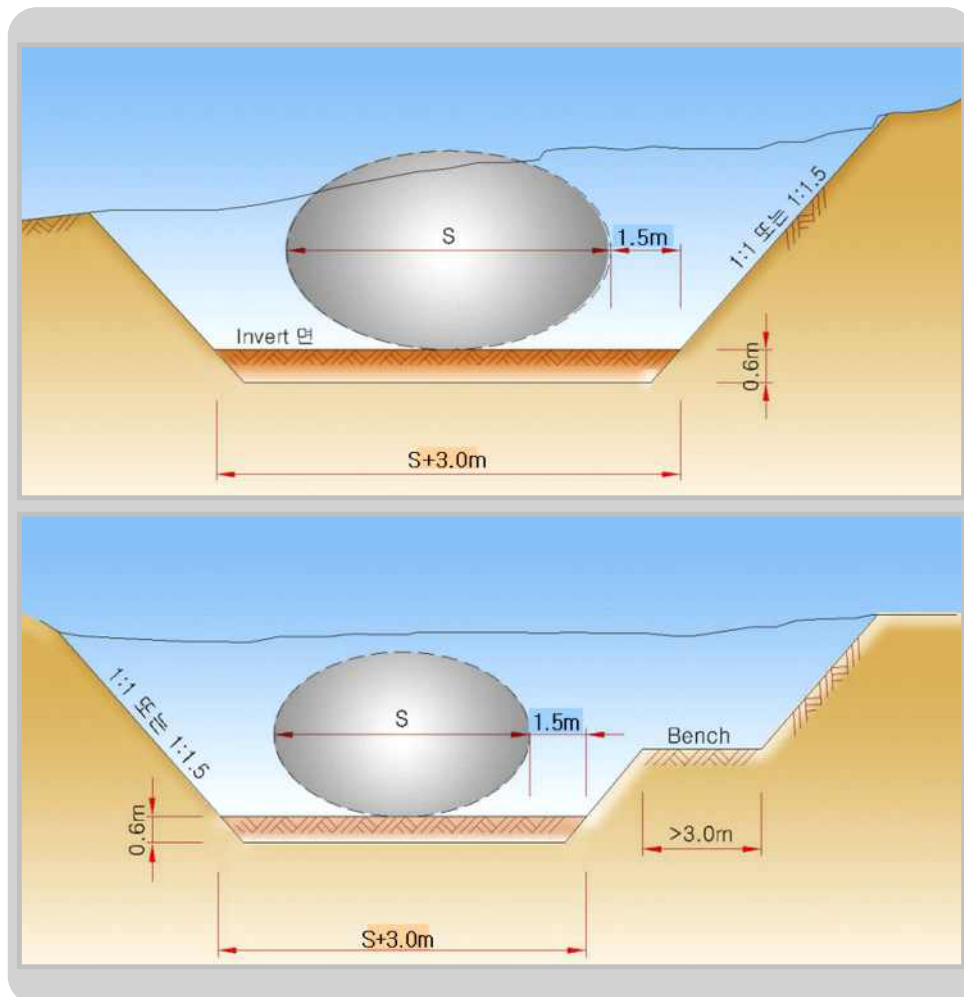
end up



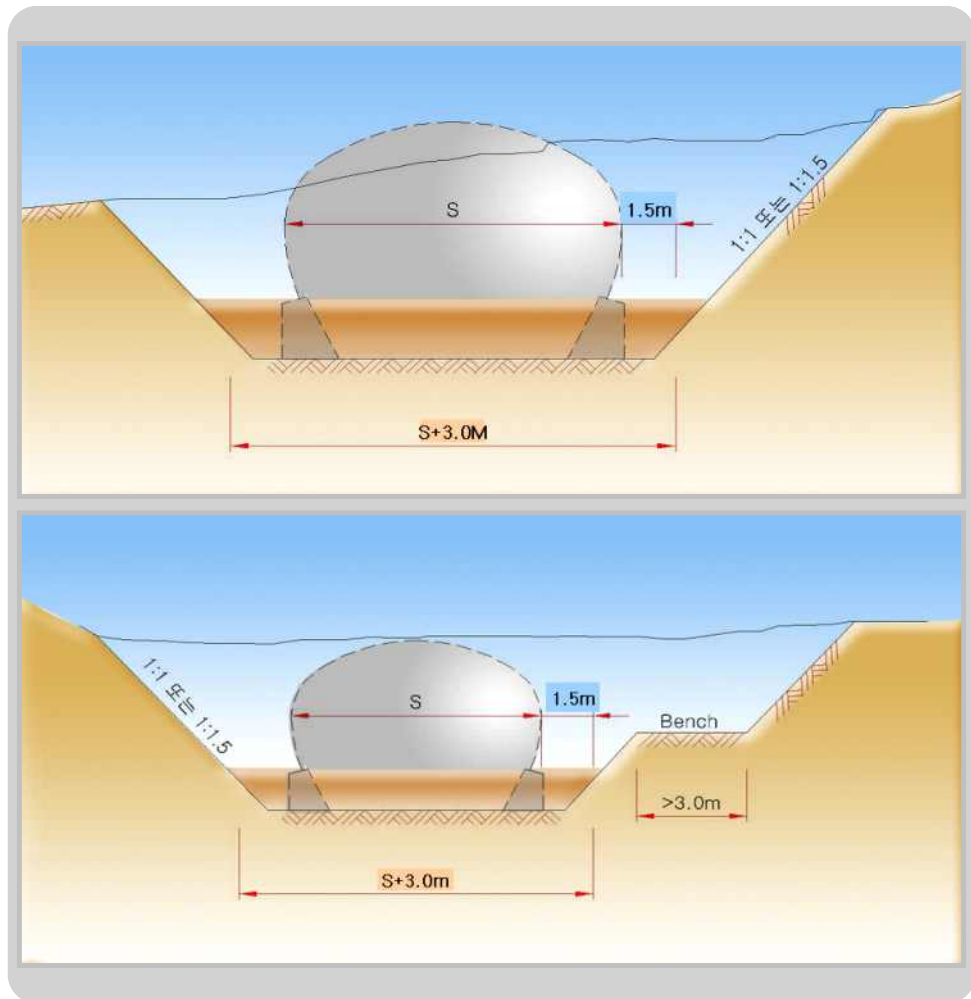
3.1 Basis excavation.

When excavating the basis for basic preparation, lean as the picture 4.3 through 4.5 shows the inclination of 1:1 or 1:1.5, and pursue balance of the excavation surface by putting a bench when the surface height is too high.

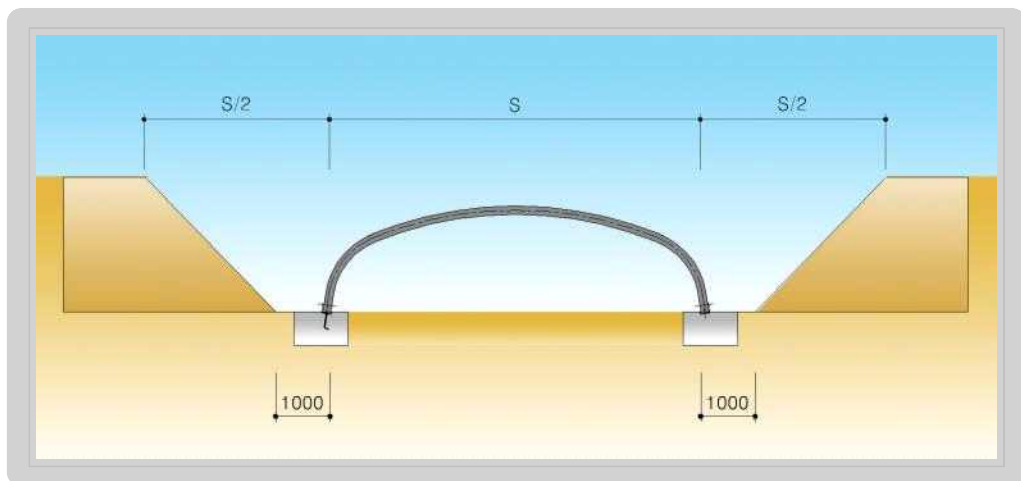
Picture 4.3 and 4.4, 4.5 all show the map of basis excavation in individual close surface and open surface structure construction. Adequate width of the bench shall be 3.0m. The width of the excavating floor shall be excavated at least 3.0m wider, and the excavating depth shall be excavated more than 0.5m higher to the structure location, substituting by quality materials. If the excavating floor is sandy basis, substitution is not necessary and only assurance should be practiced. soil cutting and assurance shall follow the domestic construction standards.



picture 4.3 basis excavation for construction of close surface structure



picture **4.4** basis excavation for construction of open surface structure



picture **4.5** basis excavation for construction of Box Culvert structure

asix shall be more than quality sand basis that does not bring excessive subsidence, and have equal support to substitute compressed basis in a specific range.

3.2 Bedding process.

Bed is a cushioning role between the basis and the steel plate material, and may use the same materials to that of the basic ones, but place soft sand of about 70~100mm where the steel plate fold is adhesive to the bed.

corrugated steel plate is magnified duration on corrosion by iron coating and shall be careful to not harm the surface by not including raw pebbles, even after the installment to the bedding area that prevents concentration force on plates.

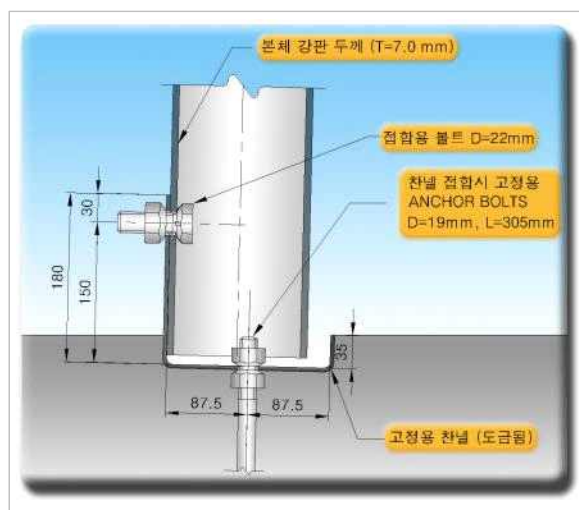
The adequate thickness for the bed installment is 60cm, and form in a same materials with the basis by compaction with sands the 1/2 size of steel plate's folding. Bed's width shall be the distance of the steel plate's change on curvature range and in cases of round form of structure, assure just enough for the haunch. Installing a bedding is more required when the lower steel plate's curvature is big, and since compaction the haunch area is difficult, forming the bedding prior to the range of curvature will enhance the construction process.

4 Basis of concrete

4.1 Connection of steel plate and the basis.

Open surface form (Arch form) structure, needs to install basic concrete structure to an exact location where it would support the steel plate wall, and check the fixed channel intervals through measurement.

1. By using base channel, connect steel plate and basic concrete.
2. Fixed channel shall be installed with laying anchor prior to the construction of concrete, and after it, anchored connection angle is usable.
3. Fixed channel shall be connected to the steel plate with right angle.

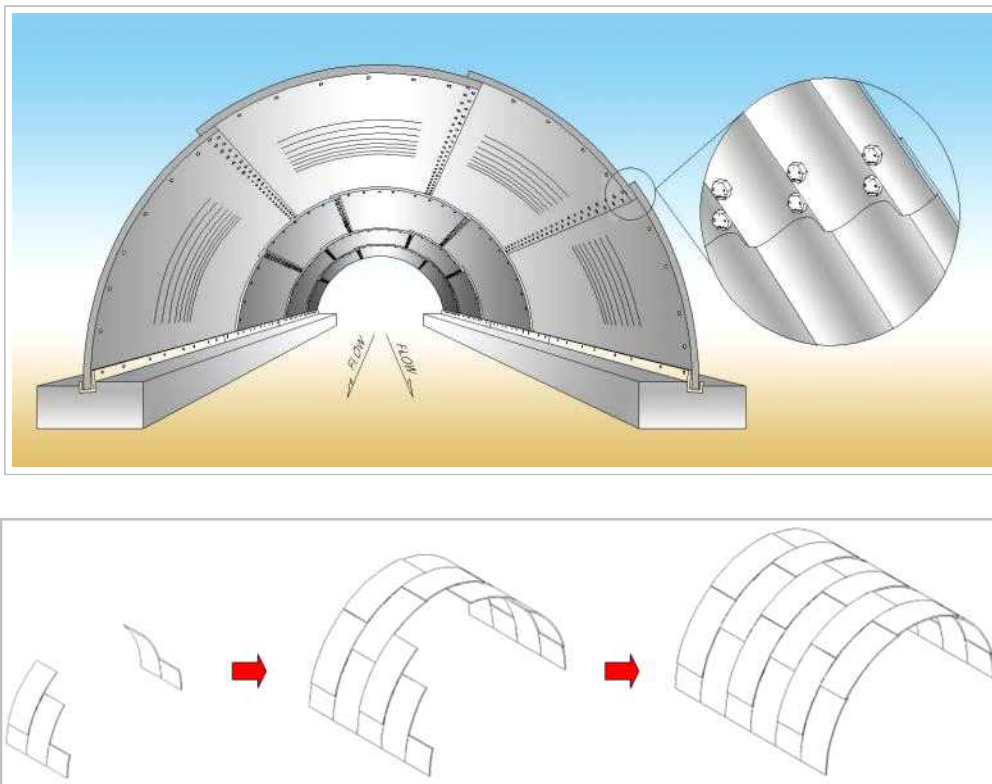


picture 4.6 basic connection

5.1 Transportation and handling of steel plates.

sheet of steel plates shall be transported and handled carefully to prevent damage, and shall not be forced by any hard substances during the installation.

Steel plate's salvage is made by concluding one side of the steel plate by a bolt with an U shaped hook, and In case of crown core area steel plate, install U shaped hook to the part of the steel plate and salvage by a crane, transporting and installing. There are additional holes to the outer side of Base Plate and steel plates which are made for salvage work of cranes, therefor bolt conclusion shall not be made.



picture 4.7 Outline of construction of steel plate.

When forming a structure by constructing sheet of plates one by one, the sequence shall start from one end forming a ring, and to the other side. The rings constructed prior presents balance to the structure and fixes a shape for it.

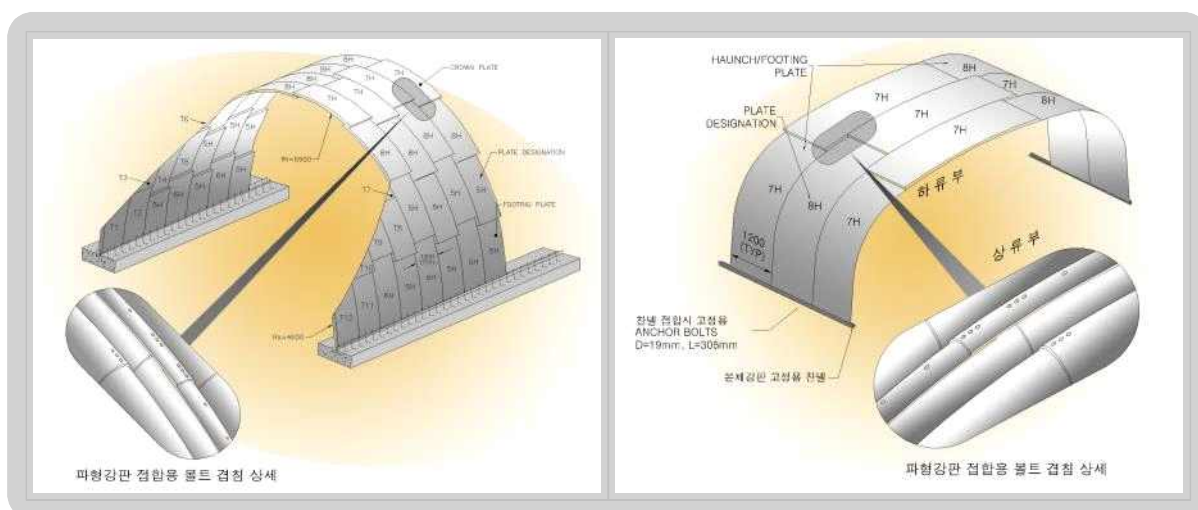
Construction the steel plates at the same time is not good and while constricting, ensure the symmetry of both sides.

When constructing, do not tighten so hard of 3~4 bolts in the center of the plate, making a room for the other plate to be connected. Bolt shall be connected from the plate's center to the side and the corner bolts shall be handled in the last stage. The process of bolt tightening shall be made from one side to the opposing side. Repetition of tightening work is required for the initial bolts may lose up, and when checking the bolts, choose 5% of any of all bolts and if 90% of those go in the standards, it's all set. Use impact wrench and when checking the bolts, use torque wrench with scales. All the bolts are to be tightened by the force of minimum, 200N·m(150FT-LBS) and maximum 350N·m(250FT-LBS).

The shape of structure's side shall be maintained even while constructing steel plates. In other words, record and check the structure's size during the construction. Under any changes, it shall be within the permissible range advised by the Fixon.

For this, use by installing cables or support, and cable holds the side from opening when the upper plate is not connected and the support prevents upper plate from hanging down by the influence of gravity. Stress is concentrated in the location of cable and support, allowing the part to deform. Therefore adequate amount of cables and support should be established for the distribution of stress. Remove cable when back filling processes to the shoulder level. Check if there is any difference of the surface phenomenon in lifting the ground level or back filling to the design surface. If it exceeds over the permitted transfer range, modify the surface by losing up the bolts and reprocessing it

5.3 Bridge Plate construction detail



picture 4.8 Bridge Plate construction detail blueprint.

Corrugated steel plate construction is made in the direction of upper to lower, and in case of tunnels, and the fixed bolts that support the curved part shall always face the basis direction that surrounds the steel plate. Start the construction in a place where the work place construction is available and with concluding first two rings. The piling up of the steel plate is as the detail A intends.

Lift the two rings constructed in prior with the crane and fix it to the fixed channel in upper part of the work place. When lifting, four points are needed and it is constructed under the director or the deputy's instruction. Straighten up the assumingly concluded two rings and place it to the fixed channel upon the basis.

Before releasing the connection of crane to the structure, construct for steel plate structure to parallel and the individual part to have right angle. Construct the remaining steel plates according to the two rings placed to the fixed channel and after constructing SIDE, HUNCH parts, construct crown parts of the steel plate. At this time, start tightening the assumingly concluded bolts after at least 3~4 rings are constructed.

Like mentioned above, after constructing steel plate, rate of torque of a bolt shall have the standard rate which is 200~350Nm. Construction may differ by the condition of the work place, for consult the work place deputy and the director for decision.

6 Earthworks (backfilling)

6.1 Characteristics of backfilling.

The materials of the backfilling shall meet the quality standards of the substituting floor materials.

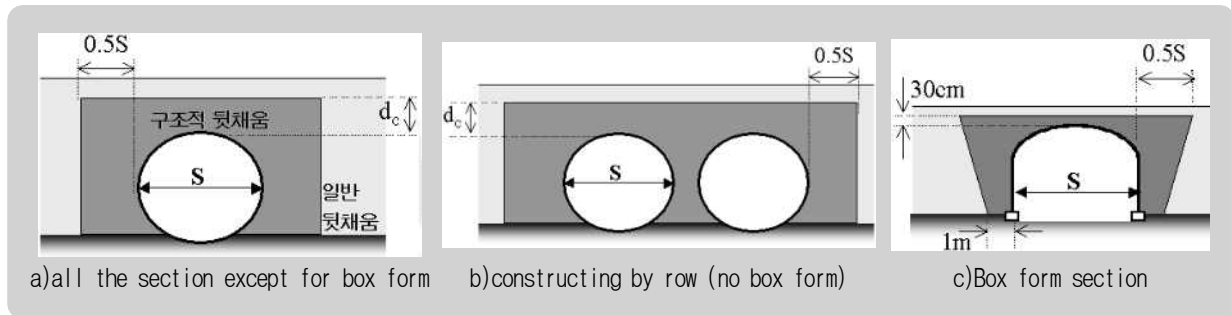
(1) Standards of the materials in backfilling

Backfilling shall use arising materials with little tendency to compress or with adequate distribution of arising molecules and equally pave it. In order for equal soil pressure to stand the surrounding area of the structure, basis and backfilling materials shall be the same or like.

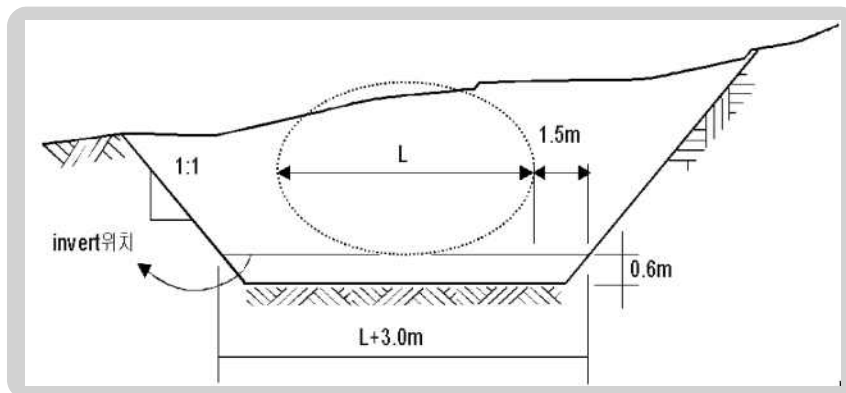
Backfilling area shall be divided into structural backfilling part where it has direct effect to the steel plate structure's move and the basic backfilling of the outer areas. When installing a structure on a raised ground level(place digging after rising ground included.), structured backfilling area shall have more than 1/2 of structure width from the utmost side of the steel plate wall, like in picture 4.8.1, and have minimum soil layer thickness (dc) of room preserved from steel plate wall's utmost upper part.

When excavating a round basis for installing a structure, more than 1.5m of space shall be

preserved from the utmost side of the steel plate wall, like in picture 4.8.1, and have more than 1/2 of structure width from the utmost side, and more than minimum soil layer thickness (d_c) of room preserved for structural backfilling area.



picture 4.8.1 structural backfilling area when installing a basis steel plate structure on a risen ground.



picture 4.8.2 structural backfilling area when installing by excavating basis ground

structural backfilling area are less compressive, formed with small pebbles, sands with adequate rising molecules certified by the work place director, and shall have the quality more to the ones in graph 6, and the maximum entrance shall not exceed the 1/2 depth of steel plate's folding. (standard diameter= 75mm) When using materials the same level to the ones in graph 4.1, prepare for freeze possibilities in winter season.

section \ class	substitute floor level(SB-1, SB-2)	material level
passing amount 200th	under 10%	under 25%
plasticity index(PI)	NP	under 10%
Unified classification symbol	GW, SW, GP, SP	SM, SP

graph 4.1 quality standards of steel plate structural backfilling

When the outer layer of the soil is somewhat thin, and the pressure condition is adverse,

Especially the terms presented in graph 4.1.1, use substitute floor or filling materials of more quality.

- ① When the soil layer is under the minimum soil layer.
- ② A case structural section requirements meet graph 7
- ③ Areas with underwater rises up to the surface.
- ④ A case structural lower basis is vulnerable (A **case of soil reform** is exception possibility.)
- ⑤ Areas with pressure aquifer layer near the earth surface

section	section requirements
standard	SPAN more than 10M
	low arch form, high arch form's curvature diameter is more than 4.5M
folded	when the sector form is bow bridge.
	All the cases in using folded forms.

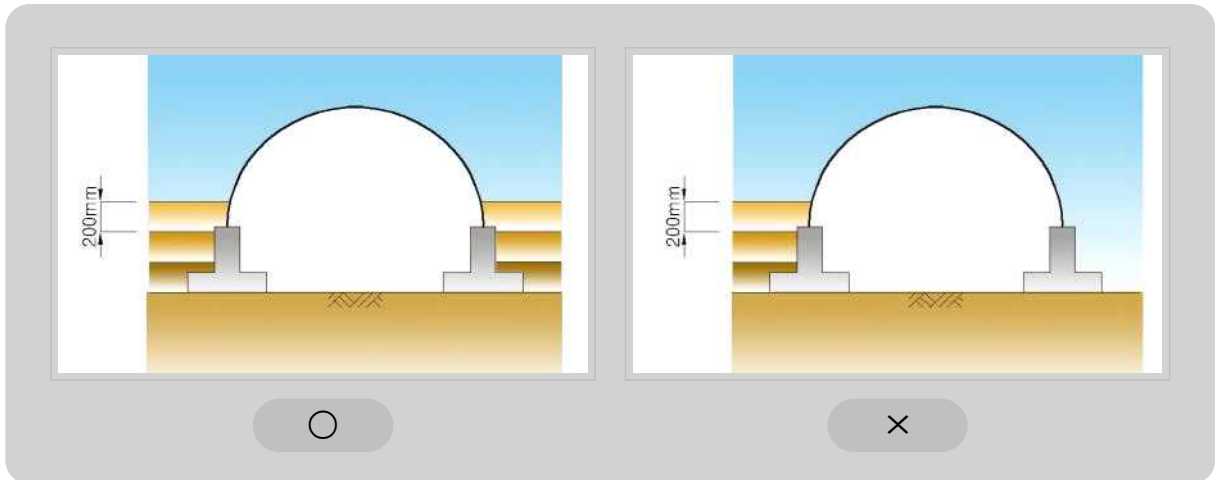
graph4.1.1 section requirements in cases of using substituting floor materials.

Structural backfilling is over the presented degree, and the maximum depth does not use the materials that exceed 1/2 of steel plate's foldings (diameter 75 mm). filling materials that contact the steel plate structure shall use folding material of under 15 mm. By the working place, in order to reduce soil pressure, folding materials shall be buried in the 1m surroundings to the steel plate. Normal backfillings are materials other than structural backfillings and can be adjusted by the work place's materials, avoiding huge rocks and if inevitable, do not place within the area of structural backfilling. Other than basic soil sand materials, fluid mortar mixture made of rising soil, water, fly ash, cements and low force materials treated with stability and etc can be used in structural backfilling area.

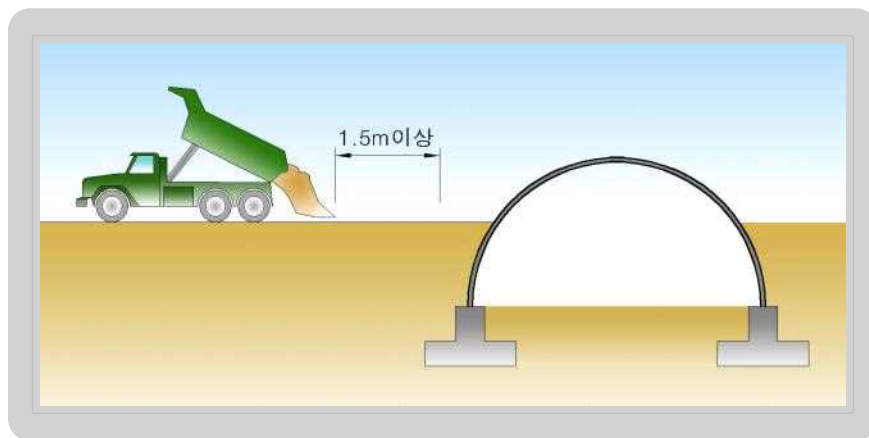
6.2 Loading backfilling materials.

- (1) Heavy equipment can be used to the permissible range advised by the engineer, and it is to minimize the effect held on the structure.
- (2) Backfilling is prohibited on the upper part of the structure, yet the side part is permitted.
- (3) Use compaction devices to proceed backfilling materials to the compaction level.
- (4) Trucks and heavy equipments are not allowed to the range of the structure.
- (5) compaction with vibrating roller, maximum layer assurance shall not exceed 200mm and not place it to the structure's section in order to reduce the effect of structural edge

parallel soil pressure.



(6) Trucks are not allowed to **within** 1.500mm from the side of the structure.



(7) Backfilling shall be constructed equally to both direction sides and the compaction level shall not exceed 400mm.

6.3 Compaction

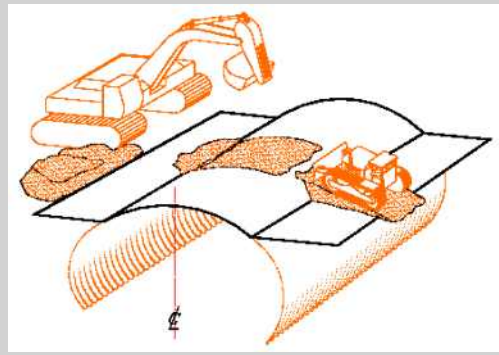
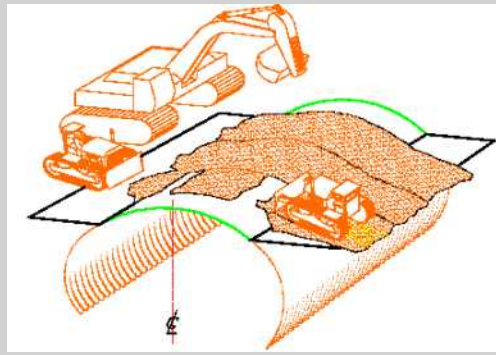
- (1) When compaction nearby the structure, use equipments like Vibrator or Tamping in order to compact the structural extension direction and the direction parallel to it.
- (2) Truck can be parked where it is more than 1500mm far from the side steel plate
- (3) Backfilling folding materials of Crown part shall be dispersed. (dropping prohibited)
- (4) Notice any deforms by continuously examining the shape of structure while compaction the side and the upper part.
- (5) Initially risen ground of Crown part shall start from the center of direction in structure length.
- (6) When compaction, backfilling folding materials shall preserve its optimum moisture content.
- (7) layer compaction shall be over 90% of minimum standard compaction density.
- (8) Through Test compaction, knowing the fact that standard compaction management is

possible, modifying single layer compaction thickness after the confirmation of directors and special engineers of the basis engineering field.

- (9) During the compaction of backfilling part, strict regulations on heavy equipments's movement other than those compaction devices within 0.6m are required. When compaction the side, compaction equipments shall move to the structure's length direction, and while compaction upper part, move to the vertical way to the length's direction.
- (10) The height difference of assurance in both sides of structure shall not exceed single layer compaction thickness(200 mm), and when the structure changes by declining earth pressure, reassure after reforming the section shape by removing the declining earth pressure.
- (11) backfilling of the structure is confirmable in terms of layer compaction by checking layer thickness to every 200mm at the corrugated steel plate structure' side, before burying backfilling materials. Degree of compaction test a every three layers.
- (12) Backfilling compaction of the side is basically done by a giant roller, and partial sections which are unable by the heavy compaction equipments shall be done by the light compaction equipments within 0.6m.
- (13) Hunch compaction process of a with no basis requires adequate compaction power, and when compaction is unavailable, do compaction by watering or rodding of high density sand or bury light concrete to the height of the hunch.
- (14) When filling corrugated steel plate structure's upper behind, the area of utmost section to minimum soil layer height thickness hall be constructed by structural backfilling.
- (15) When compaction upper area, do not vibrate compact before minimum soil layer height thickness is secured, and prohibit the transition of equipments other than compaction ones, and air-open storage of heavy materials.

6.4 Transition of structure's upper section.

- (1) When backfilling, develope backfilling materials after 3/4 of the height from the basic upper section, and compact vertical to the structure's length direction until its done.
- (2) When backfilling upper section, director and deputy must attend the event.
- (3) At least 600mm shall be secured between structure section and the track of the equipment, and 300mm from the upper part of the Crown part shall place cushion Arch and carefully construct Crown part for it is comparatively fragile. Cushion Arch shall be constructed balanced from structure's center.

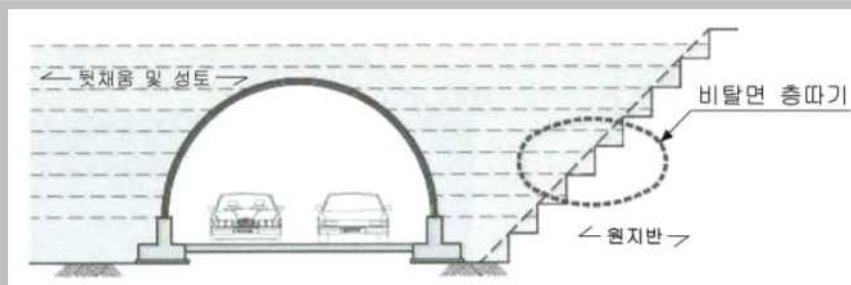


picture 4.9 Outline of compaction

- (4) Equipments for filling materials process shall not be heavier than D-4 caterpillar doser(7.0 ton) and compaction equipments shall not be heavier than BW-755.
- (5) Compaction with vibrating roller, max compaction shall not exceed 200mm and compaction equipments should not be placed in structure section for reducing structure edge to effect the parallel soil pressure .

6.5 Rising and cutting of ground and connecting part backfilling.

- (1) Rising and cutting of slope ground that contacts to the backfilling part, shall either be compacted saw like form or stair form of floor picking by matching the compaction thickness. lose parts shall be removed before construction.
- (2) When division constructing, be careful of 1st part and the 2 part's backfilling area.



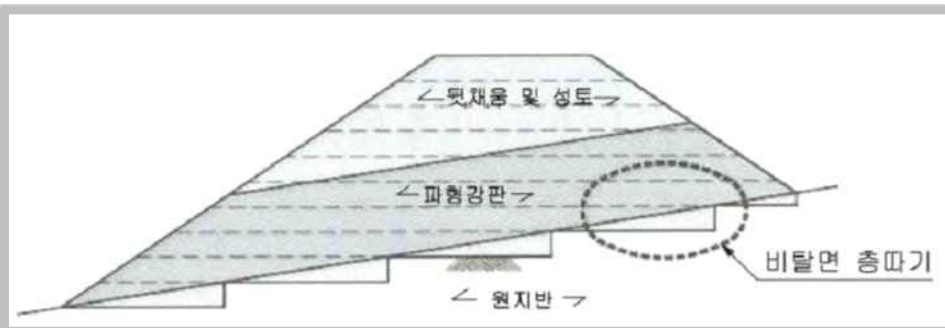
picture 4.9.1 rising and cutting of ground and connecting part backfilling.

6.6 Backfilling of vertical slop part.

- (1) Rising and cutting of slope of structure with no basis, shall secure support to the basis ground and follow picture 4.9.2 in backfilling process for unifying basis ground and

backfilling soil.

- (2) Finish backfilling as soon as possible and prevent any destruction of basis ground and backfilling soil materials by raining.



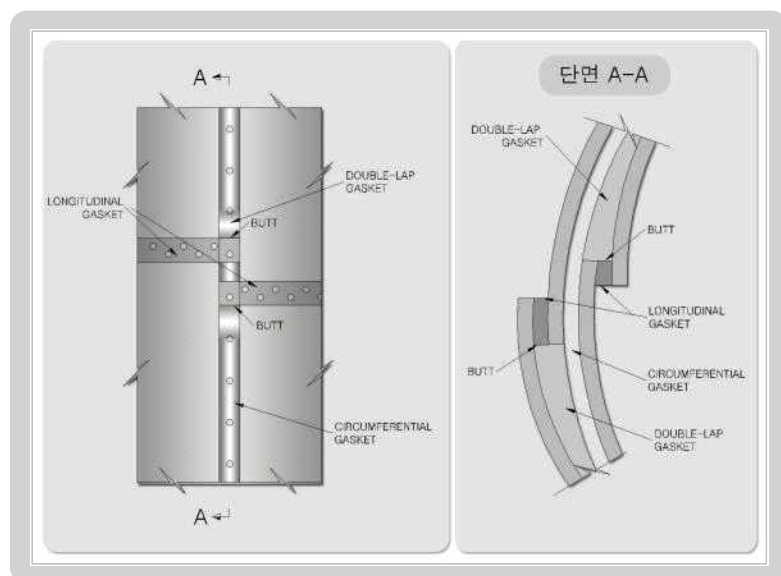
picture 4.9.2 Backfilling of vertical slop part.

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Detail in water resistant

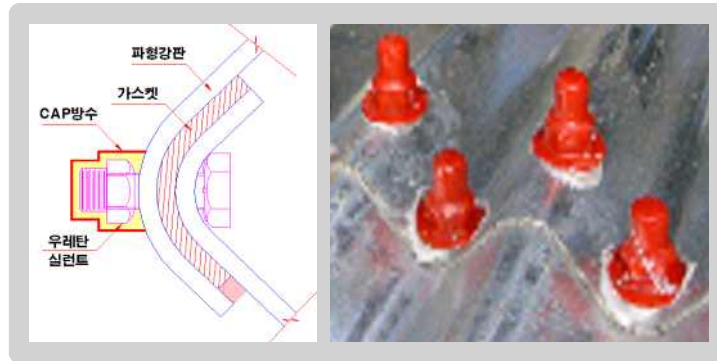
7.1 1st water resistant in folding part.

When corrugated steel plate is constructed by inserting rubber gasket for water resistant in folding part, it persists water free.



water resistant in folding part. 1st part

After inserting rubber gasket, insert urethane shell is the place of connecting bolt and then put high metaplast CAP on to harden and initiate secondary water proof process.



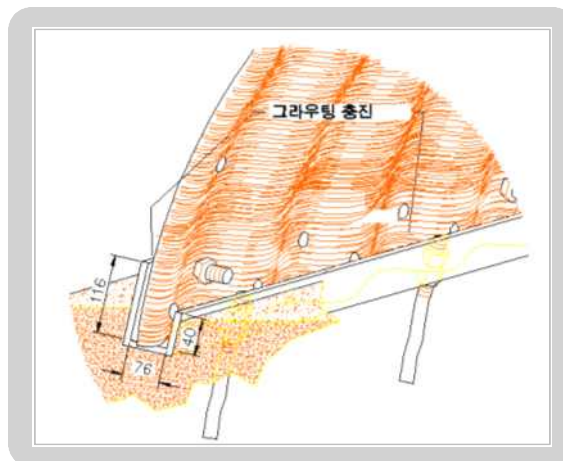
water resistant in folding part.

2nd part

7.2 Rear and basic connection part water proof

When 1st water proof work is done by water resistant in folding part, initiate secondary water proof work by doing piece water resistance for the folding part of bolt parts on rear parts.

It is important to choose materials of water resistance with flexible reactions for the corrugated steel plate is a flexible structure. Also, corrugated steel plate structure of open surface form of basic concrete require exponent between corrugated steel plate and the basic concrete's folding part. In this way, water free may enhance by inserting grouting after constructing corrugated steel plate on fixed channel sections.



picture 4.10 Outline of water proof in concrete's folding part.

8

managing drooping during construction

Right after constructing corrugated steel plate structures, during backfilling process, and right after, needs to measure the size variation of the section. When the construction is over,

before backfilling, measure the sizes of section and if the variation is over 2% of designed shape, retightening of the bolts are required.

When backfilling starts, it shall measure section sizes (more than 3 places measured in same locations)right after each layer is compacted until the time construction is over. After or during the construction, the permissible range of the deformation is the following and when the section deformation exceeds, immediately stop the construction and examine the reasons of the problem, and practice relevant procedures to bring down the deformation rate within the range.

section		Permissible deformation range
150 x 50	Arch	within 5% of the structure's height
400 x 150	Arch	within 2% of the structure's height
381 x 140	box	within 1% of the structure's width

graph 4.2 Permissible deformation range

- * structure's height (closed :RISE, open :R(upper curvature))
- * structure's width (SPAN)