EARTHQUAKE DESIGN AND CONSTRUCTION OF TAL COMPOSITE BRIDGE PIERS

T KATO[1] And Y TAKAHASHI[2]

SUMMARY

The recent lessons of structural damages occurred to a number of bridges during 1995 Hyogo-ken Nanbu Earthquake make a new bridge construction more expensive and time consuming because of the high standard of earthquake resistant design. The new expressway construction (the 2nd Tomei expressway) mainly crossing over deep valleys requires many tall bridge piers. Therefore it is required to develop the new technology which takes place of the conventional RC hollow pier. The new design concept of steel pipe-concrete composite bridge pier exhibits not only high seismic resistance in effect of ductile steel pipe and spiral high strength strand, but also a rapid construction method.

In this paper the earthquake design by the scaled model tests as well as the construction practice of the tall composite bridge pier are described.

The results and conclusions are follows:

The experimental M-Φ relation of the composite piers showed higher deformation performance than the conventional RC hollow bridge pier.

In pseudo dynamic tests the composite piers had a stable seismic behavior even after the ultimate state. And although the deformation exceeded maximum peak, the residual displacement after the earthquake was relatively small.

The analytical moment – curvature relationship of steel pipe – concrete composite piers showed lower deformation performance than the experimental results. The main reason of the low performance of the analytical models is due to the ductile steel pipe and high strength spiral strand, which cannot be coped with in the model. The results show that the contribution of steel pipes to concrete should be taken into account in order to improve the analytical methods for design.

The new construction method (namely Hybrid Slipform Method) on the composite bridge pier provides an appropriate solution for rapid construction and reduction of the skilled labor.

INTRODUCTION

After Hyogo-ken Nanbu earthquake the conventional RC hollow high pier needs a large amount of reinforcement because of high standard of seismic design. Consequently the construction cost as well as the construction period are serious subjects. The steel pipe - concrete composite pier in Figure 1 exhibits not only high seismic resistance in effect of ductile steel pipe and spiral high strength strand, but also an advanced construction method.

The characteristics of the new composite pier are as follows.

a) The composite structure is consist of single vertical re-bars outside and large steel pipes inside.
b) High shear strength is provided by inner steel pipes and high strength strands as spiral hoop. c) High ductility is provided by steel pipe as well as spiral hoop effect.
d) Concrete around steel pipes protect from buckling. In the case of buckling of outside re-bars at ultimate state, the collapse would not occur.
e) Simple section makes a better manufacturing than conventional RC hollow section.

[1] *Civil Engineering Technology Division of Obayashi Corporation, Tokyo, Japan Email: kato@o-net.obayashi.co.jp*
[2] *Department of Civil Engineering Systems, Kyoto University, Kyoto, Japan*

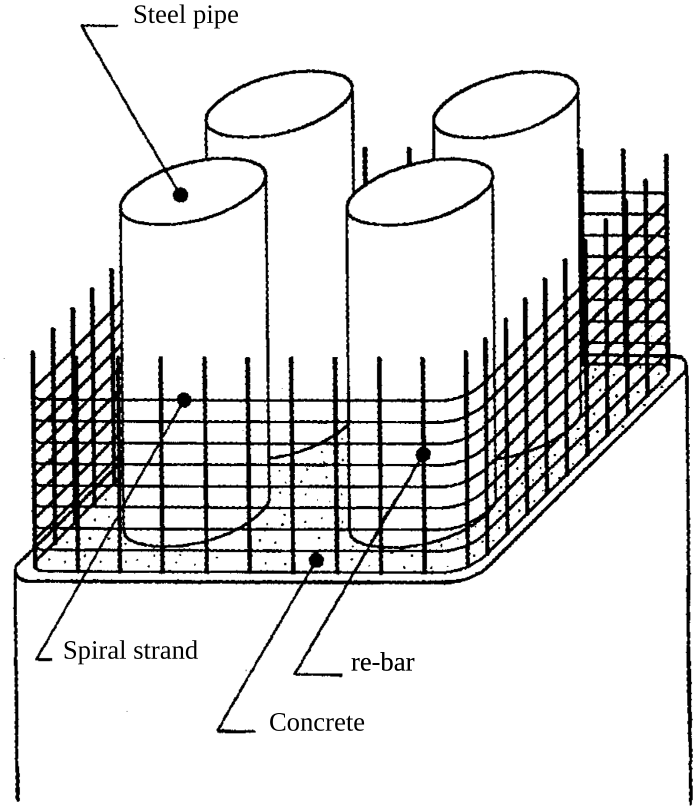


Figure 1: Steel pipe-concrete composite pier

STATIC EXPERIMENTAL STUDY OF COMPOSITE PIER

Specimen (test piece)

In order to verify the inelastic behavior of composite piers under the combined loads, static loading tests and pseudo dynamic tests were carried out. Five composite column models were tested, as shown Figure 2 - 4 and Table 1. The each shear spans are 1200mm and 600mm, the each shear span ratios are 4.0 and 2.0. As shown Figure 4, 4 pipes (diameter 76.3mm, thickness 2.8mm) and 8 re-bar (diameter 10mm) are installed in the section.

Table 1 : Test Specimens

No.	Experiment	Shear span ratio a/d	Axial load (N/mm^2)	Steel pipe ratio Pt (%)	Re-bar Ratio Pr (%)	Spiral strand ratio Peq (%)
P4-1	Static	4.0	3.5	2.53	0.56	0.18
P4-2	Pseudo dynamic	4.0	3.5	2.53	0.56	0.18
P4-3	Pseudo dynamic	4.0	3.5	2.53	0.56	0.18
P2-1	Static	2.0	3.5	2.53	0.56	0.18
P2-2	Static	2.0	3.5	2.53	0.56	0.18

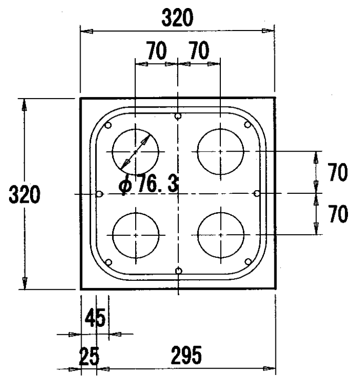


Figure 2: Section of Specimen

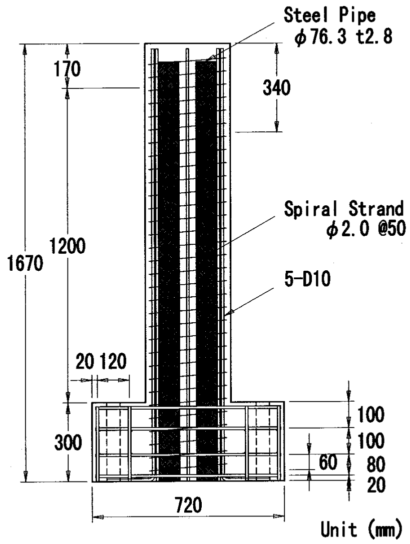


Figure 3: P4-1-3 Specimens

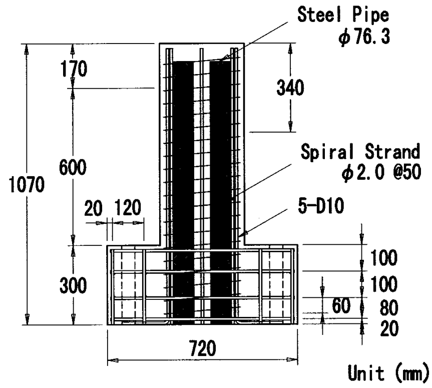


Figure 4: P2-1-2 Specimens

Experimental system

Figure 5 shows the experimental system. Lateral load is given under the fixed axial load. At the loading point lateral sift and rotation are free. The axial load is 3.5 N/mm^2.

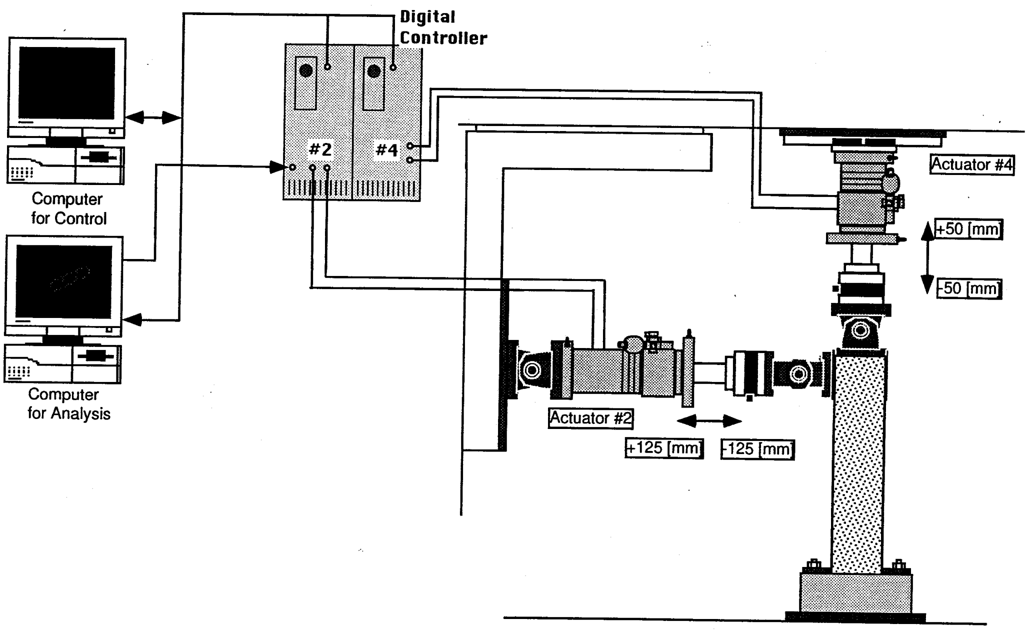
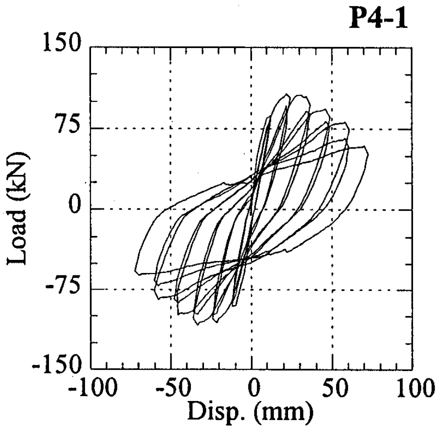


Figure 5: Experimental system

Static loading tests

1) Static loading tests for shear span ratio of 4.0(flexure failure test)
Figure 6 shows load - displacement relation. The relation curve is deteriorating from the maximum loading to the ultimate state. Thus deteriorating mechanism a typical property of this composite structure by the effect of bond slip between concrete and steel pipe. The maximum ductility factor is 7.5 superior to RC structure in general.

2) Static loading tests for shear span ratio of 2.0(shear failure test)
Figure 7 shows load - displacement relationship. The relation curve is gradually deteriorating like a flexure failure in spite of shear failure test because of shear strength of steel pipe. This result shows that the tested composite column has a high ductility and the shear strength of steel pipe should be taken account in structural design.



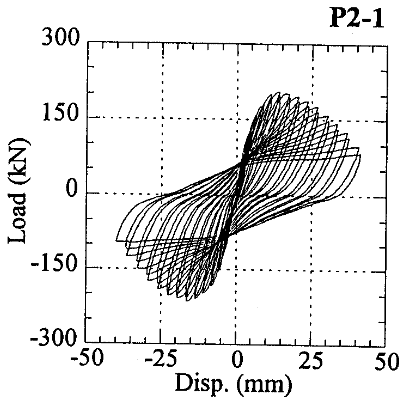
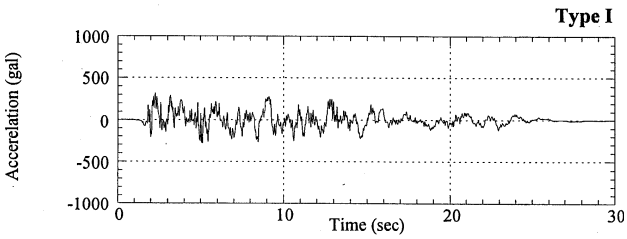


Figure 6: Load-disp. Relation (P4-1) **Figure 7: Load-disp. Relation (P2-1)**

Pseudo dynamic tests

In static loading test, the structural the basic property as loading and deformation capacity can be estimate, but the dynamic behavior of structures is not considered. Therefore the pseudo dynamic tests were carried out for the purpose as follows,
a) to observe damage level and residual displacement of composite pier directly and to estimate seismic stability
b) to compare the M-Φ property of composite pier with analytical model directly
The experimental model has a single degree of freedom with natural period of 2.0s considering actual viaduct with high pier. Moderate Kaihoku LG(Miyagi-ken Oki Earthquake 1978) and Kobe NS(Hyougo-ken Nanbu Earthquake 1995) which were inputted as shown Figure 8 and Figure 9.
The result of experiment is shown in Table 2. Although the maximum ductility factor exceeded 9.0 for each earthquake and then the covered concrete fell down, it was confirmed that the test piece of composite pier had stable seismic behavior and never been collapsed by shear failure. In addition, the residual displacement after the earthquake was relatively smaller than nonlinear analysis shown Figure 10 and 11. The experimental M-ϕ relation of the composite piers showed higher deformation performance than the analytical results as shown Figure 12 and 13. The main reason of the low performance of the analytical model is due to the property of the ductile steel pipe and high strength spiral strand, which can not be coped with in the model. This result show that the contribution of steel pipes to concrete should be taken account in order to improve the analytical models for rational design.



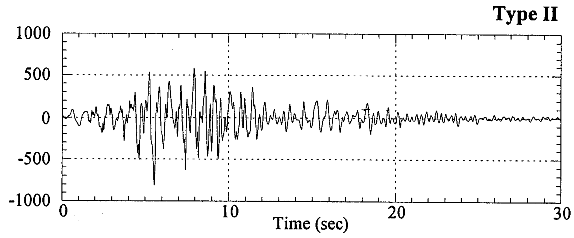


Figure 8: Earthquake acceleration of Kaihoku LG **Figure 9: Earthquake acceleration of Kobe NS**

Table 2: Results of pseudo dynamic tests

Specimen No.	Earthquake	Inputted scale	Max.inputted acc. (gal)	Max.response acc. (gal)	Max.ductility factor	Residual Disp. (mm)
P4-3	Type-Ⅰ Kaihoku	18 %	57.4	28.6	9.6	1.1
P4-2	Type-Ⅱ Kobe	18 %	146.2	31.5	9.7	12.1

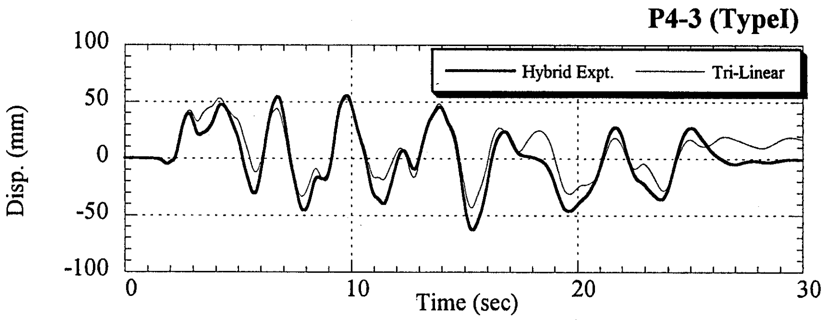


Figure 10: Comparison between pseudo dynamic test of P4-3

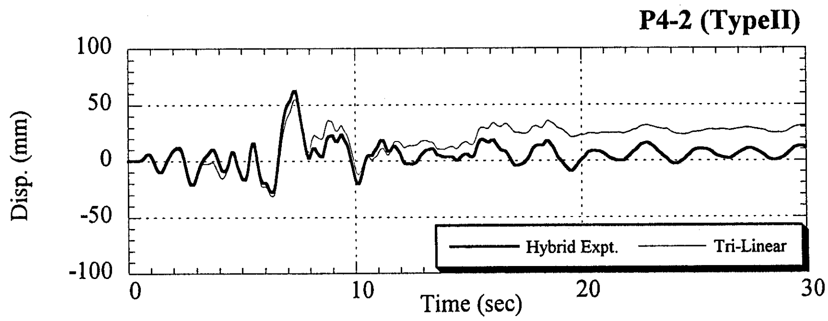


Figure 11: Comparison between pseudo dynamic test of P4-2

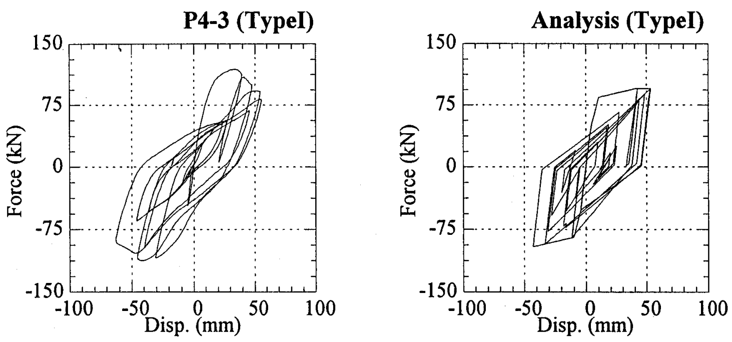


Figure 12: Load-disp. Relation of P4-3

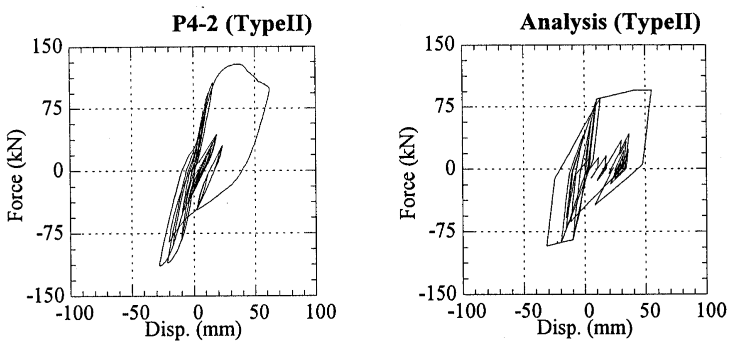
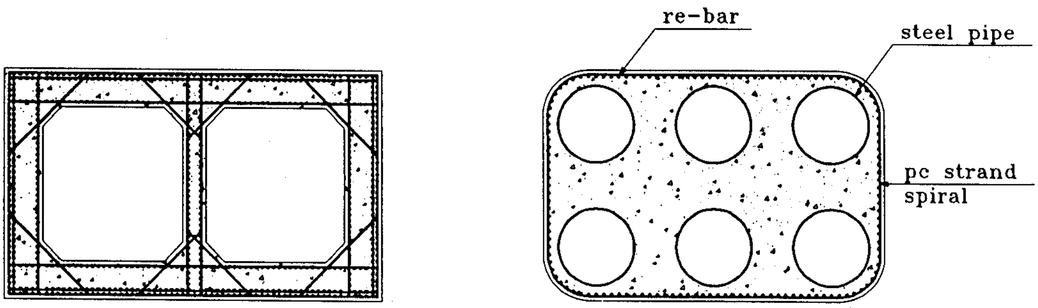


Figure 13: Load-disp. Relation of P4-2

TYPICAL CONSTRUCTION METHOD OF COMPOSITE PIER

The design of a conventional reinforced concrete pier may be an appropriate solution in terms of material efficiency and cost, while the overall construction cost as well as the construction period may not be optimum. The left hand side of Figure 14 shows a typical configuration of the conventional hollow type structure, which have one- or two-boxes. The right hand side of Figure 14 illustrates a typical cross section of the composite design, which is constructed by the steel pipes and the minimum amount of reinforcement.

A long term social trend in labor market is the shortage of skilled labor and the decrease of annual working hours. This trend enhances the engineering development for a drastic improvement of construction time and labor force required for the bridge construction. The goal of new construction method is one half in construction time and one third in labor input compared to the conventional design and jump-form construction. Figure 15 illustrates the equipment and structural arrangements of the new method.



A. Conventional hollow **B. Composite**

Figure 14: Structural concept of conventional and composite alternative

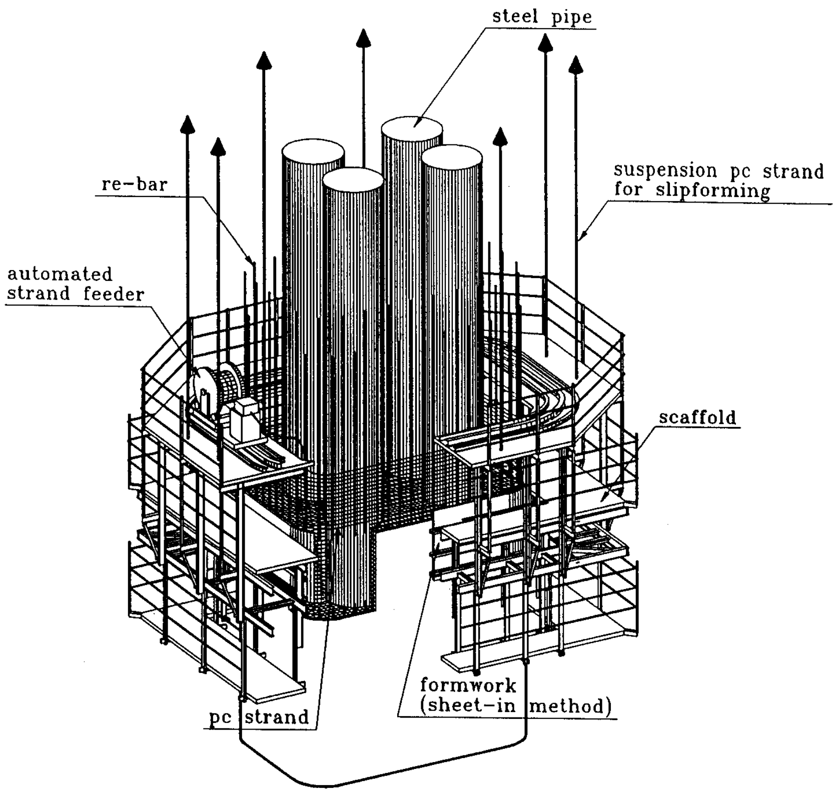


Figure 15: Illustration of Structural system and equipment of Hybrid-slipform method

The construction sequence of the method in described in Figure 16. The first step of construction is the erection of prefabricated segment of steel pipes, which length is about 10m each. Those erected steel pipes have the structural stability against the wind load till the concrete pour. At every 10m of the pipe segment erection, the group of steel pipes is strengthened by bracing, connecting each pipe together. When the erection reached to the pier top, a reaction frame is installed and fastened at the pipe head. The reaction frame supports the vertical slipforming load transmitted through the vertical tension wires made of the standard strands.

The second step follows the assembly of slipform, working decks, scaffold and jacking system(8 center hole jacks). The slipform system has four working decks. The top deck has a loop of rail track where the automated pc strand feeder runs on the track. The main deck is used for the jobs of formwork, re-bar installation, concerning and jack operation. The lower decks are for the removal of Sheet-in-Form and the work of concrete curing. In stead of a sophisticated computer control for jacking system, the manual operation is used to lifts the scaffold up 2.7m every day.

Once completed the slipform installation, the highlight of Hybrid-Slipform Method begins with the pier construction by the daily repetition of jobs sequence. The cycle consists of the jack up of the slipform system, the spiral strand installation, the placement of form, the concrete work. The height of concrete placed by each daily cycle is planned to be 2.7m. (as shown Figure 17)

The old sheet-in-form persists its position and remained to the old position of concrete poured one day before. As soon as the scaffold is settled to the new position, the new sheet-in-form is placed for the next concrete pouring. The advantages of utilization of the sheet-in-form are significant : a smooth surface finish of concrete as same as the fixed form, a drastic change of the slipforming procedure from continuous from lifting to at once lifting at any time, a better curing protection to the concrete surface, and more easier positioning of the slipform.(as shown Figure 18)

The horizontal reinforcement of spiral high strength strand is spiraled along the vertical reinforcement by using the automated strand feeder. The placement takes one and half hours by a few workers, which is needed for fastening the strands to the vertical re-bars. When the slipform reached to the fine elevation of pier structure, the working decks and scaffolds are easily lifted down together to the ground by the reversal use of jacking system. During the down ward process, any necessary finishing job for the concrete surface of pier can be done by using the working decks. (as shown Figure 19)

Practical design and construction of the composite piers are now under construction in the 2nd Tomei Project and so on. This area is mountainous and crossing deep valleys.

(1) Erection of steel pipe & welding	(2) Set of slipform & spiral strand feeder	(3) Concrete construction by slipforming	(4) Lift-down of slipform scaffold after completion

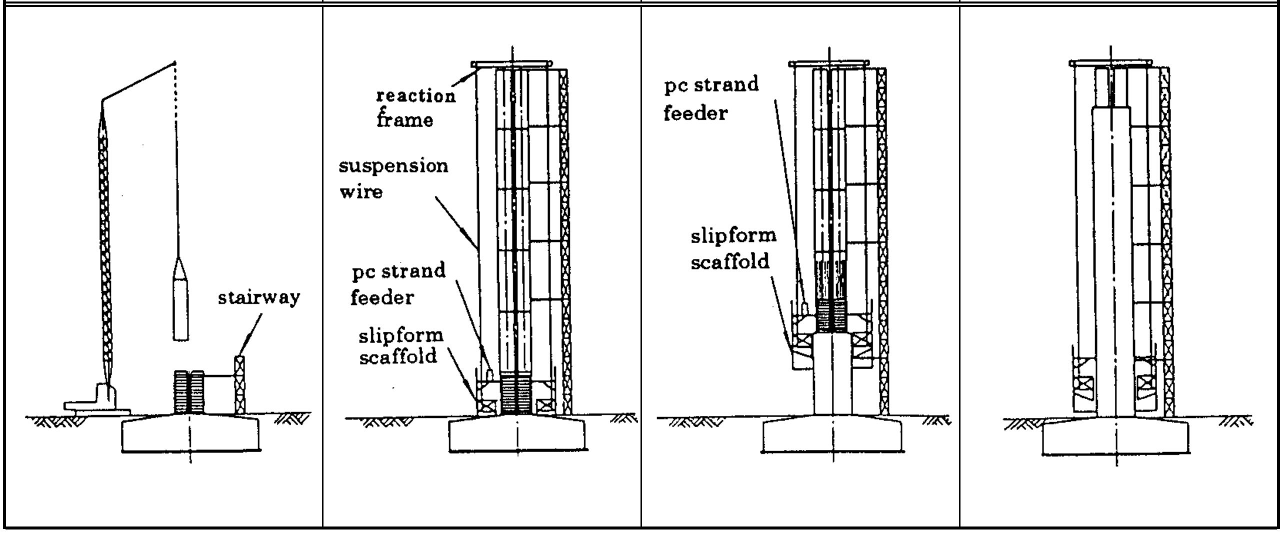


Figure 16: Construction Procedure of Hybrid-Slipform Method

Figure 17: Hybird-Slipform method construction

Figure 18: Installation of sheet-in-form **Figure 19: Automated sPIral strand feeder**

CONCLUSIONS AND REMARKS

The steel pipe-concrete composite pier and its suitable construction method (namely Hybrid-slipform Method) provides an appropriate solution not only for ductile structural performance, but also rapid construction suitable for the tall bridge pier particularly in a highly seismic region.

In pseudo dynamic tests the composite piers had a stable seismic behavior even after the ultimate state. And although the deformation exceeded maximum peak, the residual displacement after the earthquake was relatively small.

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