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Sandakan Water Supply Extension Scheme*

Seiji Kage
Staff Assistant General Manager, Regional Development Dept., Engineering & Construction Div.

Osamu Tsujimura
Staff Manager, Pipeline Engineering Dept., Engineering & Construction Div.

Yoshiaki Shimura
Staff Deputy Manager, Pipeline Engineering Dept., Engineering & Construction Div.

Hideo Shinomiya
Staff Assistant Manager, Chiba Construction Engineering Sec., Construction Engineering Dept.

Yasuhiko Ichise
Civil Engineering Sec., Civil Engineering Dept., Engineering & Construction Div.

Fumihiro Ozeki
Technical Development Div., Kawatetsu Techno-Construction Co., Ltd.

Synopsis:

Waterworks facilities with a maximum supply capacity of 62 million l/d were constructed in Sandakan, Sabah, Malaysia by Kawasaki Steel. The scope of work ranged from civil works for intake facilities to commissioning the mechanical and electrical facilities. The project was located at various sites between the distribution facility in the center to the city and the intake facility site 90 km away in a remote location. Major technical features of this project were the field fabrication and construction of steel pipe pile retaining wall, a 50-t intake pipe steel support structure, and the 20-m deep excavation for a pump well adjacent to a river bank. Special porject management consideration was given to planning and controlling the schedule by CPM, local procurement of mechanical and electrical equipment, and construction in a remote area.

1 Introduction

Sandakan is the second largest city of Sabah State in Malaysia with a population of approximately 100 000 (the location is shown in **Fig. 1**). The water supply to city was often interrupted due to the lack of sufficient underground water which was the main raw source. Sandakan Water Supply Extension Scheme—Stage I was offered for tender by the Public Works Department of the Government of Sabah to solve the water supply problem with the following scope:

(1) Fabrication of the main supply pipeline 900 mm nominal diameter and 81-km overall length).
(2) Laying this main supply pipeline.
(3) Construction of the raw water intake, water treatment and distribution system facilities.

Fig. 1 Project site

Kawasaki Steel was awarded the contract for work (3) in January 1987 and completed the job in November 1989. Kawasaki Steel's scope involved the construction of the following facilities:

(1) The raw water intake and pumping station at Bukit Garam village 90 km away from the city.
(2) The treatment plant, clean water tank, and pumping station at Kota Kinabatangan town 80 km away from the city.
(3) The distribution system, workshop and administration building, and service reservoirs located at 8 different sites in the city.
(4) The mechanical and electrical facilities for the complete water supply system from the water intake to the water distribution points.

The paper reports the execution of the civil works for

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the raw water intake and pumping station adjacent to the river bank, which is the most important technical aspect of the project, and the management to overcome the difficulties resulting from constructing various facilities dispersed in the remote locations.

2 Outline of the Project

Sandakan Water Supply Extension Scheme is divided into two stages. In Stage I, involving the facilities from the raw water intake, the treatment plant has the capacity for processing 65 000 m^3 of raw water per day, and the facilities for the clean water tank and pumping station have a processing capacity of 62 000 m^3 of treated water per day. After the facilities in the second stage are added, the capacity will be doubled. However, the sizes of the structure at the raw water intake and pumping station and of the main supply pipeline for the first stage were selected so that no further construction for these facilities would be required in the second stage. Kawasaki Steel has completed the construction of the raw water intake, water treatment, and distribution system and related mechanical and electrical facilities for the first stage. **Figure 2** indicates the site location. A substantial length of the road from the city to the Kinabatangan river was not paved, and access to the raw water intake and treatment plant became very difficult during the rainy season. **Table 1** and **Fig. 3** show the volume of work and the construction program, respectively.

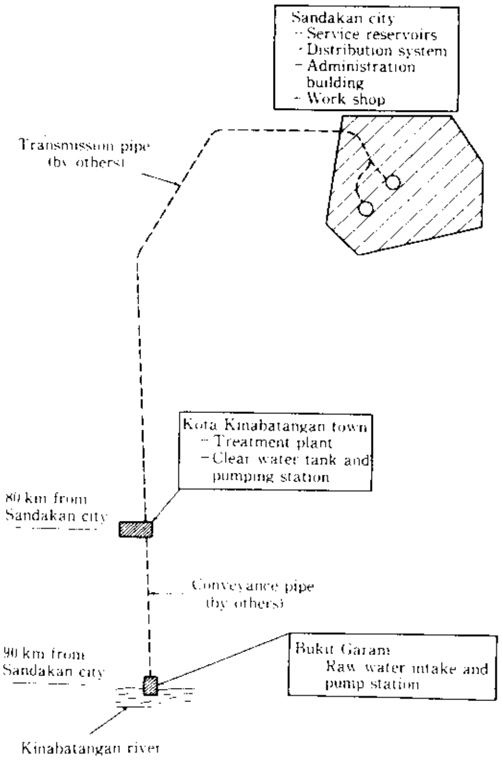

Fig. 2 Site location

Table 1 Quantities of work items

Raw water intake and pump station	
Excavation	8 400 m^3
Sheet pile (type-5L)	154 t
Steel pipe pile (OD=660, t=17 mm)	261 t
H pile	186 t
Steel pipe (OD=660/864, t=12.5 mm)	347 m
Structural concrete	981 m^3
Building floor area	320 m^2
Treatment plant, clear water tank and pumping station	
Site clearance	126 600 m^2
Excavation	51 400 m^3
Concrete bored pile (ϕ 300 mm)	2 044 m
Asphaltic concrete pavement	7 782 m^2
Steel pipe (OD=914, t=9.53/6.35 mm)	200 m
Structural concrete	4 738 m^3
Building floor area	1 980 m^2
Distribution system	
Wood pile (ϕ 150 mm)	1 597 m
Pipe bridge (at 6 locations)	105 m
Asphaltic concrete pavement	982 m^2
Ductile iron pipe (ϕ 100 to 450 mm)	23 200 m
Sluice valve (ϕ 100 to 450 mm)	103 nos
Structural concrete	809 m^3
Workshop and administration building	
Site clearance	40 700 m^2
Excavation	65 800 m^3
Wood pile (ϕ 150 mm)	123 m
Asphaltic concrete pavement	10 387 m^2
Structural steel	84 t
Structural concrete	968 m^3
Building floor area	3 210 m^2
Service reservoirs	
Site clearance	28 200 m^2
Excavation	81 700 m^3
Asphaltic concrete pavement	2 342 m^2
Structural concrete	2 195 m^3
Ductile iron fittings (ϕ 300 to 500 mm)	191 nos
Sluice valve (ϕ 300/400 mm)	12 nos
Mechanical and electrical facilities	
Submersible pump with 132 kW motor	8 units
Centrifugal pump with 400 kW motot	6 units
Centrifugal pump with 250 kW motor	3 units
Centrifugal pump with 37 kW motor	2 units
Milliscreen	1 unit
Inline mixer	1 unit
Flashmixer	1 unit
Clarifier (flat bottom upward flow sludge blanket)	2 nos
Filter (dual media sand/anthracite rapid gravity)	8 nos
Chemical dosing facilities	1 set
Instrumentation	1 set
Telemetry and radio telephone	1 set
Pipe work and fittings	1 set

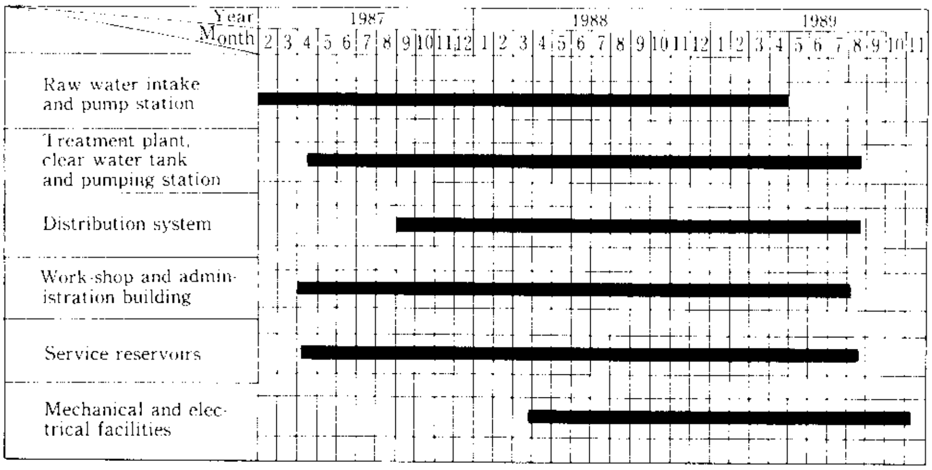

Fig. 3 Actual execution of construction

3 Technical Features

3.1 Site Fabrication and Construction of Interlocking Steel Pipe Piles (ISPP)

3.1.1 ISPP site fabrication

The client's original plan of the intake structure consisted of steel pile retaining walls to be constructed along the river bank to protect the intake pipes from flooding, driftwood, erosion, etc. (**Fig. 4**). Combined-section piles, which comprise ordinary steel sheet piles welded onto H-shape beams (**Fig. 5**), were originally designed for the structures B and C in Fig. 4. However, the following problems during the execution of work were foreseen if this original plan had been actually adopted:

- Deformation due to welding heat during fabrication of the combined-section piles
- Run-out of the piles during the driving process
- Improper pile penetration into the bearing stratum

To solve these problems, Kawasaki Steel proposed an alternative plan using the ISPP method (**Fig. 6**) and this alternative plan was accepted by the client. The ISPP method was developed by Kawasaki Steel and has been utilized in many other projects, for which ISPPs were usually fabricated in Japan and transported to the project sites. However, in this project, ISPPs were fabricated on site by utilizing locally available steel pipes to complete the work on time. The following requirements were imposed on site fabrication work to properly control the product quality:

- Welding supervision by a qualified welding inspector
- 100% radiographic inspection for circumferential welding of the main pipe
- Less than 1/1000 lateral deformation

To meet these strict requirements, a semi-automatic welding machine and turning roll system were adopted.

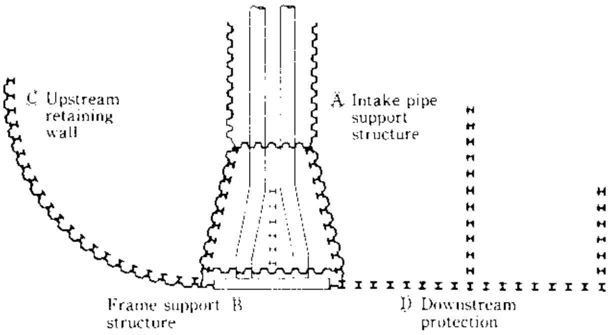

Fig. 4 Intake structure

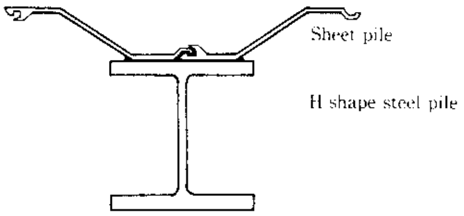

Fig. 5 Original plan "combined section pile" (changed to alternative plan)

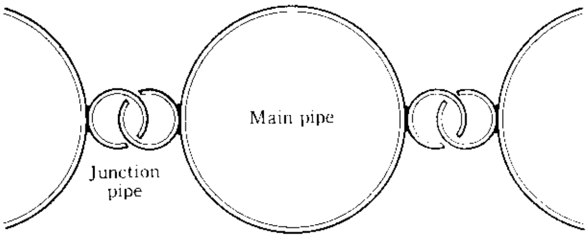

Fig. 6 Alternative plan "interlocked steel pipe pile (ISPP)", applied in water intake structure

Table 2 Comparison of combined section pile and interlocked steel pipe pile

Item	Combined section pile	Interlocked steel pipe pile
Section efficiency	○	○
Man power for fabrication	×	○
Characteristic of quality	△	○
Fabrication period	×	○
Characteristic of construction	×	○
Construction period	×	○
Total cost	△	○

Note ○: Good △: Normal ×: Bad

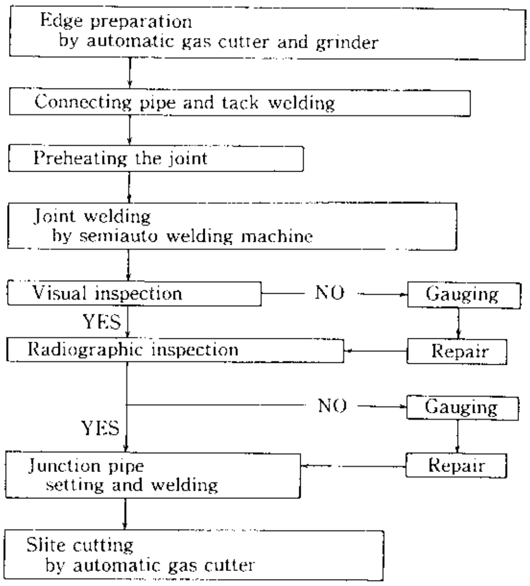

Fig. 7 Interlocked steel pipe pile fabrication flow chart

Table 2 and **Fig. 7** show a comparison between the combined-section pile and ISPP, and the ISPP fabrication flow chart, and **Photo 1** shows the site fabrication work of ISPP.[1]

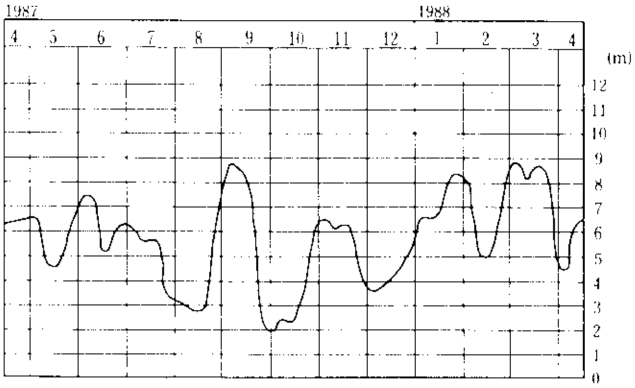

Fig. 8 Kinabatangan river water level

3.1.2 ISPP construction

The variation in the Kinabatangan river water level is large, with a 7-m difference between the dry season and the rainy season as shown in **Fig. 8**, and the river level rises rapidly due to the rainfall in the up-river district at a maximum increase of 3 to 4 m/d. Moreover, the riverbed was soft silt, and the slope was so unstable that it would have collapsed under the load of the equipment if the end-on system had been adopted for pile driving. Therefore, a temporary staging system was constructed for pile driving, using H-beams (as the bearing pile and supporting beam) and crane mats.

The upper level of this staging structure was set at RL+7 m, the design level of ISPP being RL+4 m. The past 5-year water level data were used to determine this level with due consideration to the influence of flooding and proper workability.

The soil strata around the intake structure consisted of soft silty clay and mudstone. Mudstone was used as the bearing stratum for the structure, into which ISPPs were required to penetrate more than 4.5 m to fulfill the requirements. The piles were driven by a 90 kW-class vibratory hammer down to the surface of the mudstone, and then further driven with a 4.5-t-class die-

Photo 1 Site fabrication of interlocked steel pipe piles

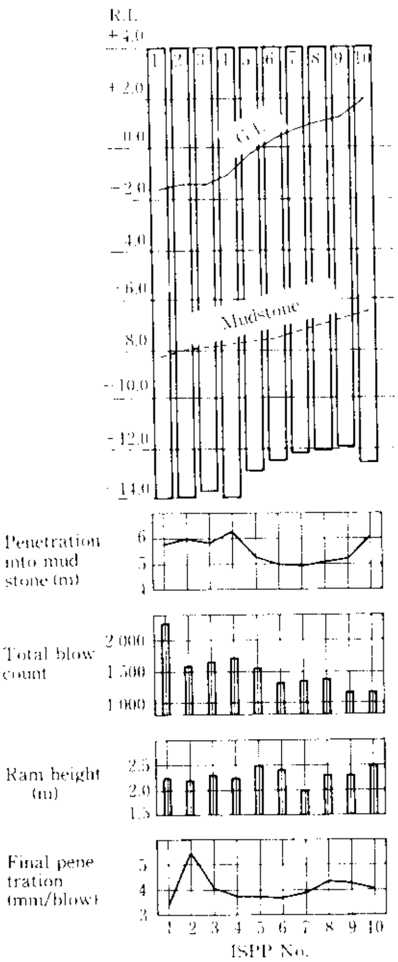

Fig. 9 Pile driving record

sel hammer. The excellent penetrability of ISPP is demonstrated by the fact that pile driving work was completed without any difficulty. Typical pile driving records are shown in **Fig. 9**.

3.2 Wetwell Construction

3.2.1 Soil condition and excavation method

The wetwell shown in **Fig. 10**, part of the raw water intake structure, is a reinforced concrete structure for conveying raw water from the river to the treatment plant. An approximately 20-m deep excavation was required to construct the wetwell, the soil strata around the construction site consisting of silty clay (N value $= 0$–24) and mudstone (N value > 50). Mudstone, the main stratum for excavating the wetwell, is similar to the Jurong Formation in Singapore and has the following properties:

(1) Unconfined compressive strength gives 700–2500 kN/m^2.
(2) Mudstone is very stiff under the unconfined condition, as indicated by the characteristic that only a few meters of penetration could be achieved.
(3) It is under the influence of rainfall and sun-curing.
(4) Soil pressure to the shoring beam increases gradually.
(5) Mudstone absorbs considerable moisture and expands as it gets wet.

Under these soil conditions, several excavation plans were compared as shown in **Table 3**,[2-4] before the excavation method with open-cut sloping sides and shoring by a timber wall was adopted. The excavation plan is shown in **Fig. 11**, and the wetwell excavation was successfully and safely completed.

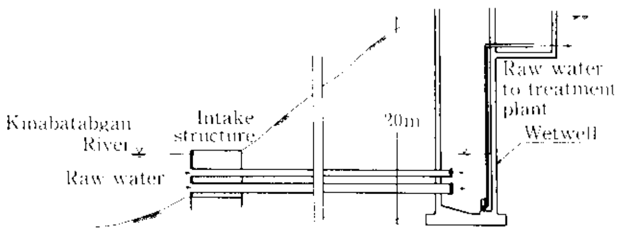

Fig. 10 Raw water intake structure

3.2.2 Site measurement system

During the wetwell construction, the two site measurement systems shown in **Fig. 12** were employed to ensure safe excavation work. One method was the monitoring system for the excavated pit, using inclinometers, surface movement pegs and water level meters installed to check the behavior of the slope sides and

Table 3 Comparison of excavation method

Excavation method	Execution	Economy	Safety	Remark	Judgement
Open-cut with slope sides	○	△	○	Open cut area becomes bigger than project work area.	○
Open-cut with shoring	△	×	○	Difficult to get sufficient retaining wall pile penetration into the mudstone stratum	△
Open-cut with earth anchoring	×	△	×	Lack of reliance on applying this method to the mudstone stratum Necessary to procure the special equipment	×
Open-cut with slope sides and shoring with timber wall	○	○	○	Easy to procure required steel material and timber for walling	◎

Note ◎: Very good ○: goob △: Normal ×: Bad

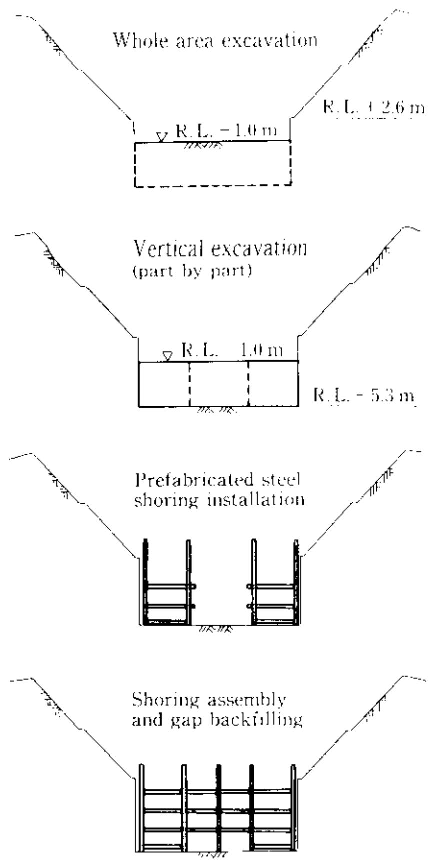

Fig. 11 Excavation execution plan

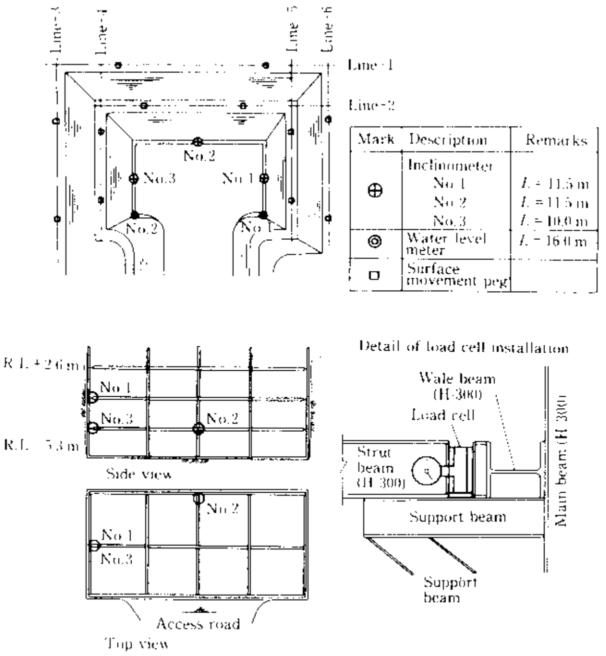

Fig. 12 Measurement system arrangement for excavation work

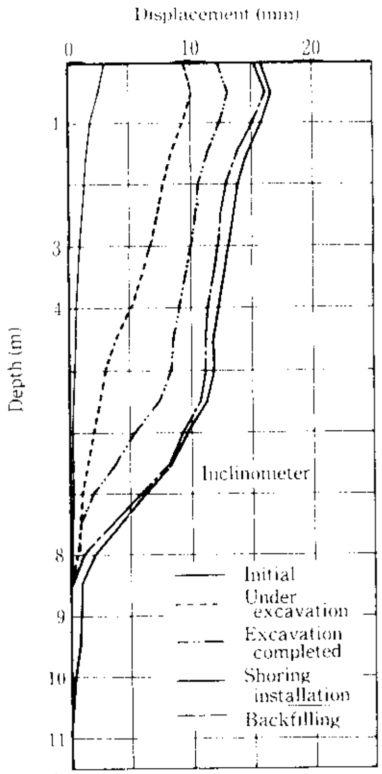

Fig. 13 Inclinometer data

excavated vertical walls. The other method was the monitoring system for the shoring to observe the actual shoring beam stress and frame behavior. Three load cells were installed between the shoring strut beams to detect the danger of wall collapse. **Figure 13** shows an example of typical inclinometer data measured during the pit excavation work. The allowable deformation of the vertical excavated walls was set to be within 20 mm.

3.3 Site Fabrication and Installation of the Intake Pipe Support Structure

The intake pipe support structure is a steel frame holding four lines of intake pipes. It is approximately 50 t in weight and submerged below the surface of the water, the general view being shown in **Fig. 14**.

A typical method for this kind of structure is to prefabricate in a factory and then transport and instal as a whole, this method being employed for offshore jacket work. Such a method was not feasible in this project for the following reasons:

(1) The river was not large enough to transport the structure as a whole.

(2) Taking the weight of the structure into consideration, the availability of special equipment for installation was not feasible.

In addition, the installation work had to be done within an uncertain short period due to unforeseeable variation of the river level.

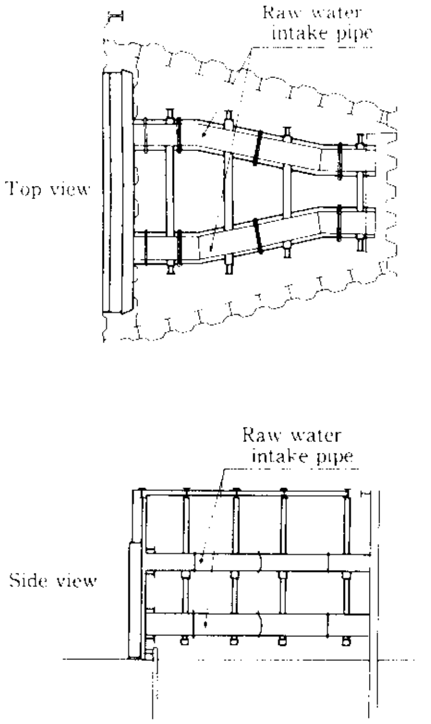

Fig. 14 Raw water intake structure

After due consideration of these restrictions, the work was done by prefabricating frame units in the site fabrication yard, assembling completely above the river and then lowering into the river.

The maximum weight of the prefabricated frame units was determined by the crane capacity (50 t). The quality of site welding work was assured by conducting the welding procedure test and welders qualification test strictly in accordance with British Standards requirements. Prefabricated frame units were assembled on temporary support beams by welding so that the assembled structure was positioned 3 m above the designed installation level.

Although the synchronized jacking-down system, which has high reliability for this type of installation work, was studied, the assembled structure was lowered into position by using 10-t chain blocks, after reviewing the workability, cost and allowable time for procuring alternative equipment. The assembled structure was lifted by the chain blocks, the temporary support beams were cut and removed, and the complete assembly lowered slowly to the designed level (**Fig. 15**). The load distribution and level control system during lowering were carefully examined to ensure complete safety.

The adoption of this method had the following advantages:

(1) The quality of welding could be assured because most of the essential welding work was completed in the site fabrication yard during the prefabrication stage.

(2) Workability was high because under-water welding did not need to be used.

(3) Variation in the water level did not have a significant effect on the whole construction program because the time required for final installation was short.

(4) No procurement of special equipment was required.

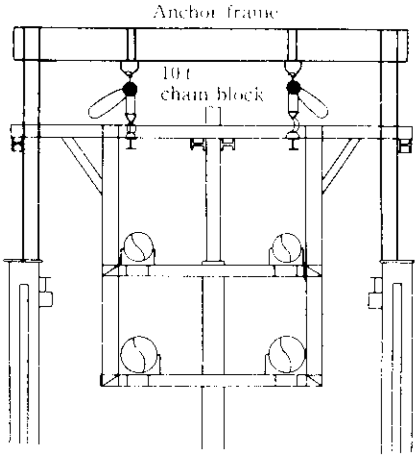

Fig. 15 Intake structure installation

4 Project Management

An essential factor in any construction job is that the work should be completed as specified in the contract. When the contract is administered under international contract conditions such as FIDIC, overall project management of all aspects including the conditions of contract and cost is vital.

In the Sandakan Water Supply Extension Scheme—Stage I, a high level of project management was required to overcome the difficulties resulting from the need to construct various facilities at dispersed sites in remote locations. The following were paid special attention to overcome any difficulties during the execution of the work:

(1) Schedule control by the network analysis method

(2) Procurement of mechanical and electrical equipment and materials

(3) Construction management in remote locations

4.1 Schedule Control by the Network Analysis Method

Schedule control has to achieve the following in a construction contract:

(1) Progress Measurement

It is used to find any difference between the as-planned schedule and actual progress so that appropriate measures can be taken to recover delays.

(2) Adjusting the Construction Period

An as-planned schedule can be affected by such fac-

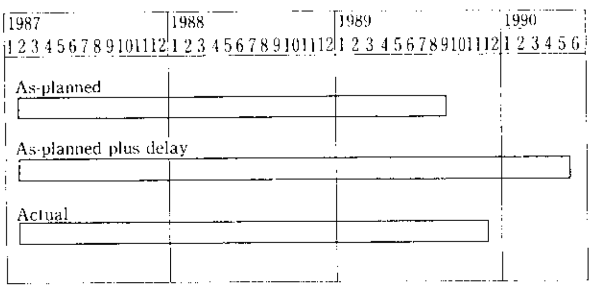

Fig. 16 Critical path method (CPM) analysis for construction period

tors as design changes and force majeure during the execution of the work. Consequently, the construction period needs to be adjusted after a quantitative analysis of such factors.

Progress measurement during this contract was initially conducted by the bar chart technique. However, this technique was not enough for a quantitative analysis of various factors on the as-planned schedule, and the network analysis method, which can express the sequence and interrelationship of various work items, was subsequently introduced.

Figure 16 is the simplified presentation of the results of the network analysis, in which the length of the critical path is shown for the as-planned, as-planned plus delay, and actual schedules. The as-planned plus delay schedule was developed by incorporating various factors into basic as-planned schedule.

A comparison between the as-planned and as-planned plus delay schedules shows that the theoretical difference in period was 8.7 months. However, the difference between the as-planned and actual schedule was only 2.7 months, because the work was speeded up by introducing more resources than those planned at the beginning of the work. As a result, an adjustment of 2.7 months was made to the construction period in this project.

4.2 Procurement of Mechanical and Electrical Equipment and Materials

Figure 17 shows the flow diagram for the water supply project. The design of the whole system was made as simple as possible because the main facilities were located in remote areas. The most suitable, mechanical and electrical equipment and materials were procured from 10 different countries. The administration capability for overseas procurement affects not only the quality and schedule, but also the profit from the project. In this regard, different vendors were compared for product quality, delivery time, ease of maintenance and price, before the most appropriate vendor was selected. **Table 4** shows an example of the sources for various mechanical and electrical equipment such as valves.

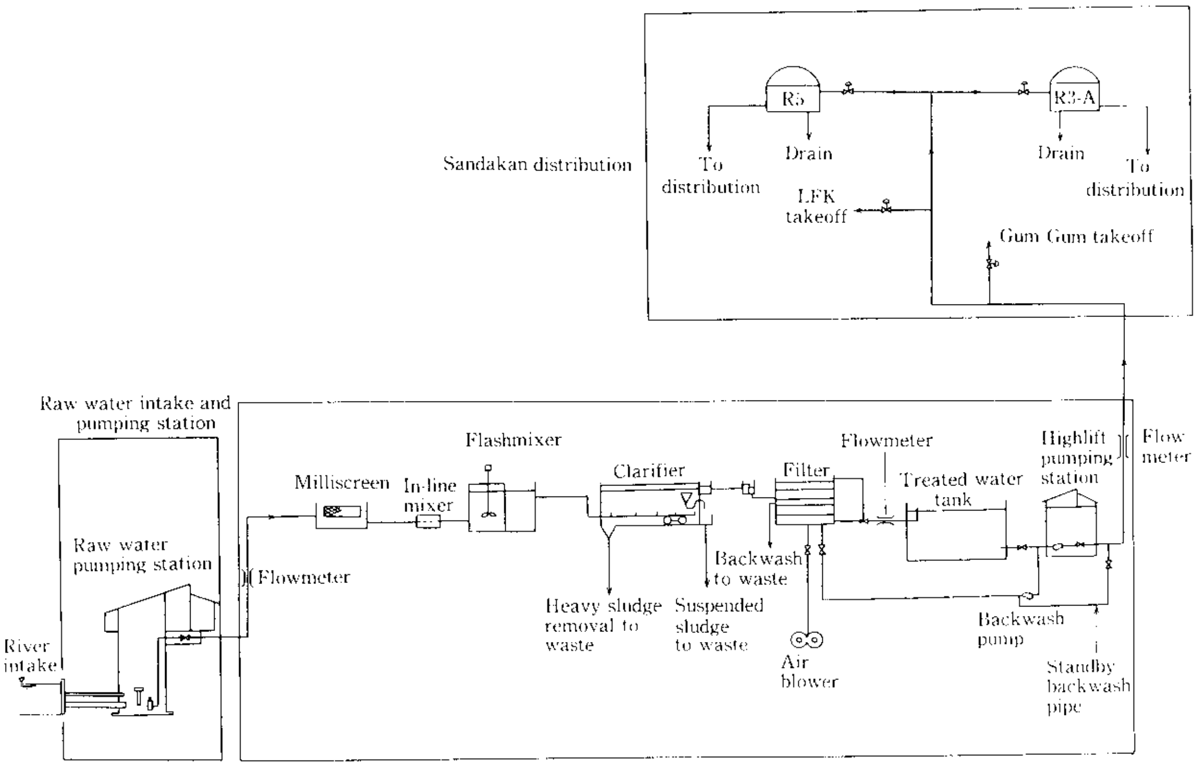

Fig. 17 Flow diagram of Sandakan Water Supply Extension Scheme Stage I

Table 4 Procurement of various mechanical and electrical materials

Materials	Country
Sluice valve ($\leq\phi$ 300)	China
Sluice valve ($\geq\phi$ 350)	Thailand
Butterfly valve	Thailand
Check valve ($\leq\phi$ 250)	Thailand
Check valve ($\geq\phi$ 350)	Japan
Air valve	Malaysia
Penstock	Malaysia
Flat valve	Thailand
3-way valve	U. S. A.
Flexible joint	Japan
Specialized valve	Canada
Electric actuator	U. K.

4.3 Construction Management in a Remote Area

4.3.1 Project organization

As shown in the site location plan (Fig. 2), project sites were widely dispersed, and it was necessary to set up site offices at 6 different places. This accordingly increased the number of staff needed to administer the project. In addition, the factors peculiar to each project site had to be well considered to employ local personnel. A project organization was therefore established that used local staff in such key positions as project engineer and project administrater.

4.3.2 Transportation planning

One of the most critical aspects for effective cost management of a project in a remote location is the transportation planning for equipment and materials. In particular, the transportation of bulk materials such as aggregate for concrete has a great effect on the overall cost. Transportation by dump trucks commonly used for bulk materials was costly and questionable in process control due to the condition of the access roads, which became impassible during the rainy season. Consequently, aggregates were transported on the rivers by barge to achieve a stable supply at reasonable cost.

5 Conclusions

Various aspects of the Sandakan Water Supply Extension Scheme–Stage I were reported. The results are summarized as follows:

(1) The client's original plan for an intake structure consisting of the combination of steel sheet piles and H-shape beams was replaced by an alternative plan that used ISPPs (interlocking steel pipe piles). Site fabrication and placement of ISPPs had advantages in respect of workability, quality and cost.

(2) A comparison between four methods was made for the construction of the 20-m deep wetwell. After due consideration of the soil conditions, construction safety and cost, the method using open-cut sloping sides and shoring with timber walls was selected, and monitored by inclinometers and other equipment.

(3) The intake pipe support structure (50 t in weight) was prefabricated in a site fabrication yard and then lowered below the surface of the water, despite unforeseeable wide variation of the river level.

(4) The construction period was adjusted after a quantitative analysis of the effects of various factors on the as-planned schedule by using the network analysis method.

(5) A comparison of many vendors was made for mechanical and electrical equipment and materials in respect of quality, delivery time, ease of maintenance and price. As a result, international sourcing made a great contribution to the quality of purchased equipment and materials, and to the profit of the project.

(6) Special steps were taken to employ local staff's key positions, and in planning transportation for bulk materials such as aggregate because of the construction activities in the remote areas.

The special features of this project are the construction of the raw water intake structure on an unstable river bank and the project management used to construct of various facilities on dispersed sites in the remote areas. It is the authors intension to make good use of the experience gained in similar future projects.

The authors express their gratitude to all persons concerned for the strong cooperation that was given in completing the project.

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