WAYANG WINDU GEOTHERMAL POWER STATION – REINSTATEMENT OF LANDSLIDE DAMAGED GEOTHERMAL FLUID SUPPLY PIPELINES

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ABSTRACT

Wayang Windu geothermal power station, located in hilly terrain about 40 km south of Bandung, West Java, Indonesia, delivers 227 MW of electricity into West Java transmission grid.

On 5th May, 2015 a major landslide affected the area north of the power station. Multiple pipelines that convey geothermal two-phase fluids to the separator station were severely damaged, forcing shut-down of the power station. Following the immediate responsibility to address social and environmental disaster management concerns, the Power Station Owner initiated a project to safely reinstate the damaged pipelines and restart the power station. PT. Geotechnical Engineering Consultant (GEC) carried out a preliminary geotechnical assessment of the slide and an initial evaluation of the options for pipeline reinstatement. PT. Geoindo provided topographic and ground investigation (drilling) services. AECOM NZ provided engineering services for redesign of the pipelines, pipe supports and foundations, as well as geotechnical overview of ground investigations. Construction was carried out by PT.Cipta Bangun Nusantara (CBN).

A critical project requirement was to provide a safe design that could be constructed speedily using available materials, in order to avoid the inherent delays in sourcing long-lead items. Accordingly, a 2-stage design and construction program was proposed. The aim of the initial stage (Stage-1) was to accomplish early reconstruction of part of the pipelines, utilising reclaimed materials from other (less critical) areas of the steamfield to enable the power station to restart as soon as possible, albeit at a reduced capacity. Full reconstruction using new materials was to be completed in Stage-2, to regain the full generation capacity.

With meticulous planning and holistic project management, the Project Owner achieved the challenging milestones. The power station was restarted on 9th September, 2015 at 85% of full capacity and was back to 100% generation on 31st December, 2015.

1. WAYANG WINDU GEOTHERMAL POWER STATION

Wayang Windu geothermal power station is situated in a picturesque setting amidst tea plantations at an elevation of 1500-2100m above sea level. The location is in the district of Pangalengan, West Java and about 40 km south of Bandung city.

The power station has been delivering electricity into the West Java transmissions grid at an average plant availability of over 98% since commercial operation of Unit-1 (110 MW) commenced in 2000 and Unit-2 (117 MW) commenced in 2007.

Geothermal two-phase fluid is gathered from several production wellpads located in the northern part of the steam field and conveyed in multiple cross-country pipelines to the central separator station, located about 4km from the wellpads. Cyclone type separator vessels separate two-phase fluid into vapour (steam) and liquid (brine) phases. Dry saturated steam is supplied to the power station located about 1 km from the separator station and separated brine is conveyed, by gravity, to reinjection wellpads about 8 km away in the southern sector of the field.

2. LANDSLIDE ON 5TH MAY, 2015

A major landslide (Figure 1) occurred upslope of Margamukti village, Cibitung Residency on the afternoon of 5th May 2015. The landslide, possibly triggered by heavy rain over the previous few days, occurred rapidly and without much prior warning. It had a severe impact on the local community. The village population had to be evacuated and subsequently relocated to an alternative settlement area.

The length of the landslide from its crown to the toe of the debris flow is about 800m. The landslide destroyed about 400m length of 3 major production pipelines (Figure 2) conveying geothermal two-phase fluids to the separator station, forcing a total shut down of the power station.

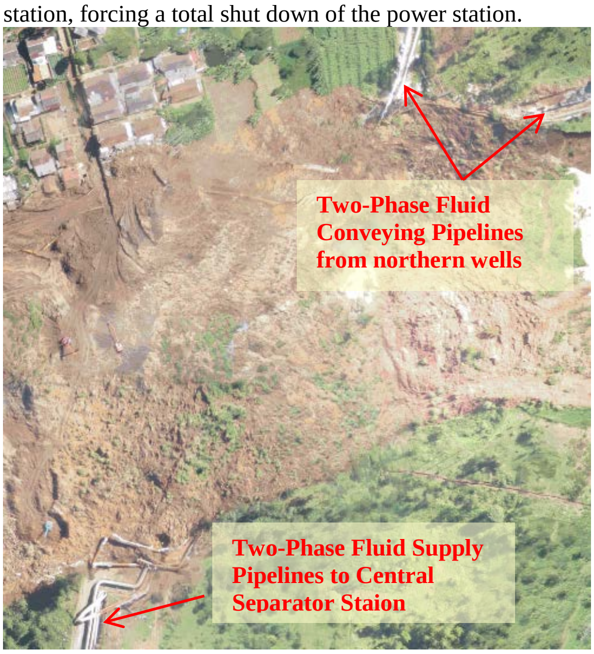

Figure 1: Part of Landslide Debris Field

Figure 2: Pipelines Damaged by Landslide

3. CONCEPT PLAN

After attending to the immediate social responsibility to support the local community, the management of Wayang Windu power Station (hereinafter referred to as Project Owner) formed a task force to set out a concept plan to safely reinstate the pipelines and restart the power station with minimum delay. The task force comprised the Project Owner and design consultants engaged to investigate the failure and design remedial works.

Since it was clear that the reinstatement pipelines would need to cross the landslide-affected area; it was, therefore, essential that the design ensured that the new pipelines and structures would be able to withstand any potential future debris movement. At the same time it was very important to the Project Owner, from a production perspective, to adopt a design that could be speedily constructed to minimise generation losses.

An initial meeting attended by the Project Owner, GEC and AECOM was held to review the various potential options, as listed in Table 1, and establish the preferred methodology/ concept design.

Table 1 : Concept Design Options

	Option	Pros / Cons
1	Reroute the pipelines away from the landslide-affected area	Pro: Low risk of future debris movement. Con: Involves very long lead time for land acquisition (due to legal and administrative issues).
2	Use a pipe bridge (suspension / tower/ other type) to span the new pipelines across landslide-affected area	Pro: Elevated pipelines (>5m above ground) and foundations outside landslide-affected area. Con: Very high construction costs and time.
3	Pipes on elevated support structures	Pro: Pipes above debris movement (>3m clearance above ground). Relatively easy and fast construction possible, at a lowest cost. Con: Support foundations are located within the landslide-affected area requiring a foundation design that can withstand future debris movement.

From a critical review of these options and considering aspects such as future risk, construction time and costs involved etc. the Project Owner selected Option #3 (i.e., pipes on elevated supports) as the preferred option.

4. PRECONSTRUCTION WORKS

4.1 Recovery Work Planning

Having selected the preferred option, preconstruction/ enabling work was undertaken, which aimed at:

- Making a safe work zone to reduce risk of subsequent landslide movement and to ensure safety of people to carry out construction activities for the pipeline reinstatement;
- Cleaning of debris, removal of damaged pipelines;
- Preparing necessary facilities/ infrastructure for reinstatement pipeline construction activities;
- Reclaiming existing NPS 36″ pipes from areas that would not be utilized during Stage-1 and mobilise reclaimed materials to the reinstatement area.

4.2 Enabling Work

The main tasks to ensure a safe construction work zone included:

- Draining of the landslide pond located below the headscarp since water infiltration in that area could destabilize the slide debris;
- Reshaping of the headscarp and upper part of the debris to improve the slope stability safety factor to an acceptable value;
- Daily monitoring of the landslide to provide warning of any ground movement;

The step-by-step sequence of preconstruction works is illustrated in Figure 3.

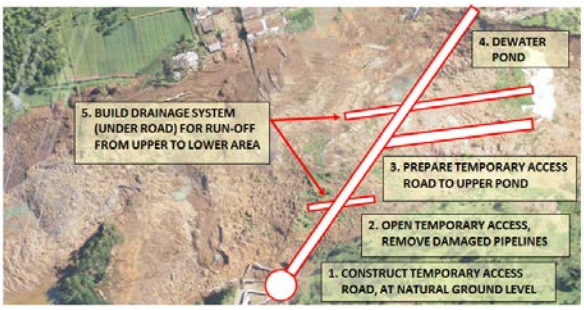

Figure 3: Step-by-step pre-construction works plan

Figures 4 to 8 show activities during pre-construction works, namely, removal of damaged pipelines, development of necessary infrastructure for construction works, such as road, workshop and lay down area.


Figure 4: Clean-up of debris on the upper landslide area


Figure 5:Temporary drainage from the upper pond


Figure 6: Damaged pipeline removal


Figure 7: Reshaping to stabilize the upper part of debris


Figure 8: Access road preparation

5. GEOTECHNICAL ASSESSMENTS

A significant constraint to an alternative pipeline route that avoided the area of failure debris was the inordinately long time required for new land acquisition. Consequently, the pipeline route was constrained substantially to the original pipe corridor with small slivers of land (either already owned by the Project Owner or which could be traded with adjacent land owners) to suit the final pipeline configuration. The selected reinstatement pipe route, therefore, was necessarily across the landslide affected area, requiring an assessment of the stability of the debris/ failure scarps and appropriate design of the support foundations suitable for the geotechnical conditions.

PT GEC, Bandung was engaged by the Project Owner to undertake a geotechnical assessment of the landslide and to propose and supervise a geotechnical investigation of the proposed pipeline route. PT GEC was also responsible for proposing the form and design of the foundations for the reinstatement works. The failure debris comprised mainly sandy and silty soil derived from weathering and hydrothermal alteration of andesitic lava and pyroclastic deposits. Groundwater pressures were high in the toe region of the failure, producing a relatively fluid and fast moving debris.

Based on their assessments, PT GEC selected a foundation solution for pipe trestle and anchor supports located on failure debris (refer Section 10: Foundations). The foundations consisted of fixed head pile caps on 1200 mm diameter reinforced concrete bored piles, either 25m or 35m in length. Each bored pile was cased with a steel shell for the uppermost section (approximately 15m) of its length. Piles located on adjacent intact ground to tie-in with the existing pipelines were designed by AECOM. These were 1200 mm diameter reinforced concrete piles and 15m in length.

The basis for PT GEC selecting this pile system on debris was: a) the thickness of unconsolidated failure debris being about 10m; b) the debris may continue to move, which would impose lateral loads on the pile system. Consequently, the long axis of the pile caps was oriented parallel to the general direction of any future debris flow. This meant that for a total of 11 pile caps, the pipe supports were at an angle of 45° to the pipeline axes (Figure 9).

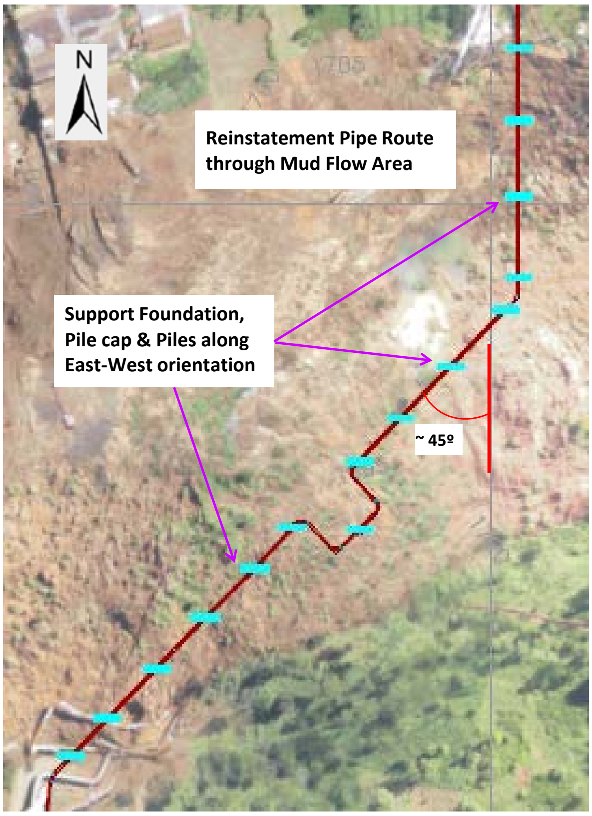

Figure 9: Orientation of Pipe Supports

PT GEC also recommended that the underside of the pipelines be elevated at least 3m above ground level through the landslide debris to allow for possible future debris flows to pass under, rather than impinge on the pipelines.

A total of 9 inclinometers were installed in selected bored piles and 2 inclinometers installed in adjacent investigation drillholes for monitoring possible movement of the debris materials.

6. DAMAGED PIPELINES

The following main pipelines, damaged by the landslide, were reinstated:

- NPS 36″ (914 mm outer dia) pipeline conveying geothermal fluid from northern wellpads MBD;
- NPS 36″ pipeline conveying geothermal fluid from eastern wellpads WWQ & MBE;
- NPS 48″ (1219 mm outer dia) pipeline conveying geothermal fluid from northern wellpads MBA & MBB;

In addition to these reinstated pipelines, the design of pipe supports and foundations allowed for (space provision and strength capacity) a potential NPS 48″ pipeline for future (Unit-3) extension of the power station.

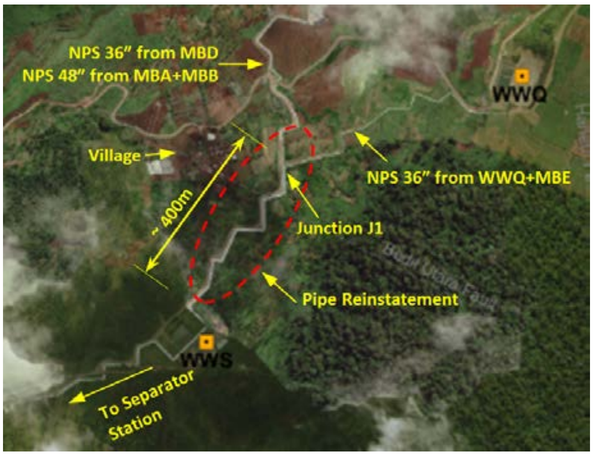

Figure 10: Pipeline Configuration (before Landslide)

6. REINSTATEMENT STAGES

The lead time associated with procurement and delivery of large diameter pipes was between 4 to 8 weeks. Thus, in order to minimize the time period to restarting the power station, a 2-Stage work program was planned.

In Stage-1 (also known as “temporary piping” stage), only the 2 x NPS 36″ reinstatement pipelines would be installed, i.e., excluding the NPS 48″ reinstatement pipeline. The NPS 48″ line installation was to be carried out in Stage-2 (also known as “permanent piping” stage) of the project.

The NPS 36″ pipes required to install the Stage-1 pipelines were reclaimed from the existing fluid conveying pipeline from the comparatively less productive wells on wellpads WWQ/MBE. In Stage-1, the NPS 48″ pipeline conveying fluids from the more productive wells on wellpads MBA, MBB and MBD was connected, at North and South ends, to the NPS 36″ reinstatement pipeline that was designed for eventually transporting fluids from the WWQ/MBE wells. Thereby, on completion of Stage-1, the power station could be restarted on part-load using fluid from wellpads MBA, MBB & MBD only (i.e., without fluid from WWQ & MBE).

For Stage-2, the NPS 48″ pipeline for conveying fluids from wellpad MBA/ MBB was reinstated using new piping materials and the dismantled pipe lines of WWQ/MBE were reinstalled. On completion of Stage-2 construction and over a short plant shutdown, the temporary connections between NPS 48″ (MBA/MBB) to NPS 36″ (WWQ/MBE) pipelines were dismantled, permanent connections established and the power station was restarted at full load.

The concept of the stage-wise pipe reinstatement programme is explained in Figure 11 below.

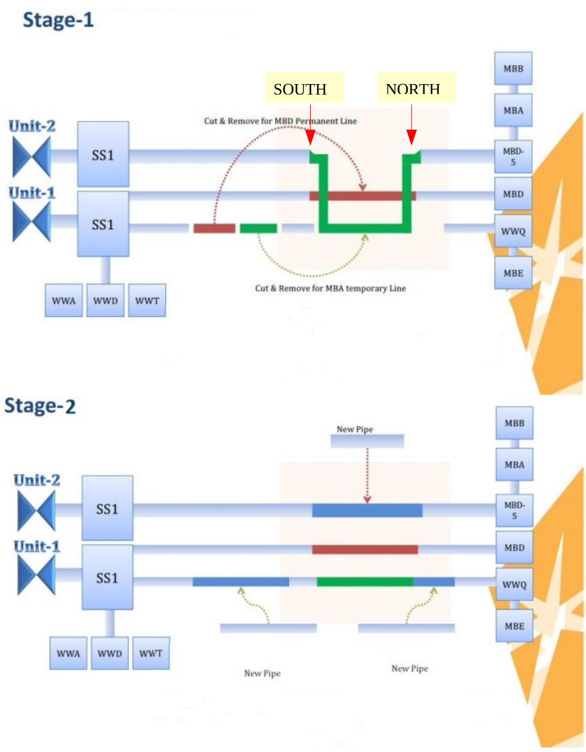

Figure 11: Reinstatement Stages – Schematic Diagram

7. EXTENT OF REINSTATEMENT PIPING DESIGN

The Project Owner carried out extensive field inspections to check the integrity of existing pipes, supports and foundations outside the landslide area. Based on the field check results, the extent of reinstatement piping design and installation was identified for sections of pipelines within 3 existing anchors – known as "North", "South" and "East" anchors, as shown in Figure-12.

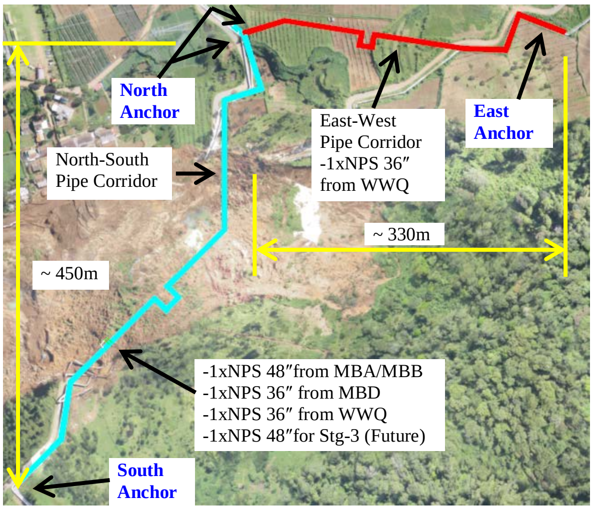

Figure 12: Reinstatement Piping Design Limits

8. PIPELINE DESIGN

8.1 Design Pressure and Temperature

The same design pressure, temperature and piping material specifications, as established in the original development of the power station, were followed (Figure 13). The "Junction J1" in Figure 13 signifies the location of a set of pressure balancing lines that interconnect the two-phase mains.

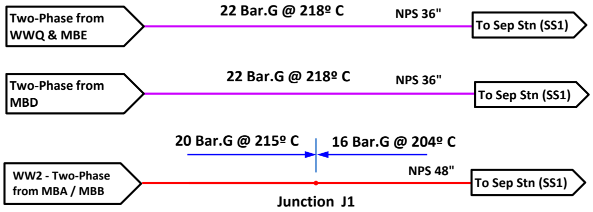

Figure 13: Reinstatement Piping Design Pressure

8.3 Design Code (ASME B 31.1) Compliance

The reinstated pipelines were accurately modelled between pipe anchors and analysed for Code compliance using the AutoPIPE computer analysis program. Two design models, one for the Stage-1 (temporary pipeline) and the other for the Stage-2 (permanent pipeline) configurations were developed. The design pressure, temperature and other loadings (e.g., seismic, slug forces etc.), for multiple operating cases, were applied to the design model and the computer analysis was carried out to predict developed stresses in the piping system. The stresses at all points of the piping system were found to be within the allowable limits stipulated in the Code.

9. PIPE SUPPORT STRUCTURES DESIGN

Pipe support trestles were mostly elevated trestles of the structural form shown in Figure 14.

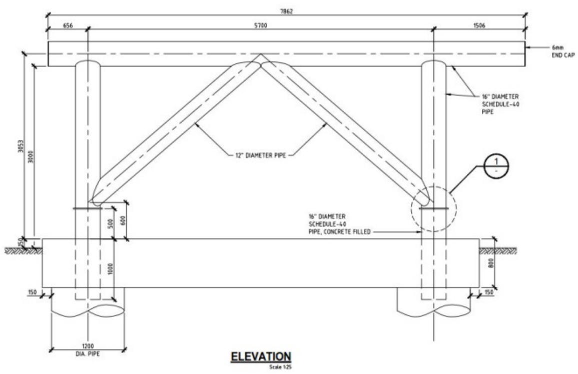

Figure 14: General Form of Pipe Support Trestles

Wherever possible, immediately available materials were used to construct the support structures. These were 16″ diameter Schedule-40 pipe sections for pipe support beams and columns, and 12″ diameter Schedule-40 pipe sections for diagonal braces. On some trestles, longitudinal forces required the use of 30″ diameter columns and 24″ diameter pipe support beams. All joints were fillet welded, and all columns were filled with concrete up to the flange connections just above the top of the pile caps to assist longitudinal load transfer into the pile caps.

Anchor supports consisted of pipes of the same diameter as the 2-phase pipes being supported (36″ and 48″) and cantilevering off the pile caps. These too were partially filled with concrete to assist load transfer into the pile caps.

10. FOUNDATIONS

As previously mentioned (Section 5: Geotechnical Assessment), the foundation solution proposed by PT GEC consisted of fixed head pile caps on either 25m or 35m long reinforced concrete bored piles of 1200 mm diameter. Each bored pile was cased with a steel shell for about the top 15m of its length.

PT GEC hypothesised that the movement in the debris may continue and therefore recommended that the axis of piled foundations in landslide debris be oriented parallel to potential ground movement, for a so called "knife effect" (Figure 9). PT GEC calculated that the ground movement would require part of the resistance of each foundation system, with the remainder being available to resist above-ground loads, such as pipe operational loads and seismic loads in their various combinations. Pile reinforcement consisted of 36xD32 axial bars with D13x200 hoops reducing to 16xD32 (D13x200) hoops over the bottom 7m and 12m respectively for the 25m deep and 35m deep piles.

The foundation design by AECOM for the pipe supports on unaffected ground on the north and south sides of the landslide consisted of 15m long, 1200mm diameter reinforced concrete piles. Reinforcing consisted of 20xD32 axial bars with D13x200 hoops.

11. SPECIAL DESIGN ISSUES

11.1 Special Geometry for Pipe Support Frame

As outlined in the previous sections, the reinstatement pipelines through the landslide area were routed at an angle of about 45º to the north-south direction. The three parallel pipelines ran with a uniform fall in the direction of flow. The undersides of the 3 parallel pipelines were levelled at any plane square to the pipe axes, and therefore it became necessary that the top member of the support structure frame would have to be sloped to support adjacent pipelines resting at slightly different levels (gradually increasing/ decreasing from one outer pipe to the other). The profile of the support frame top member was accurately designed and fabricated to suit the varying levels of adjacent pipes (Figure 15).

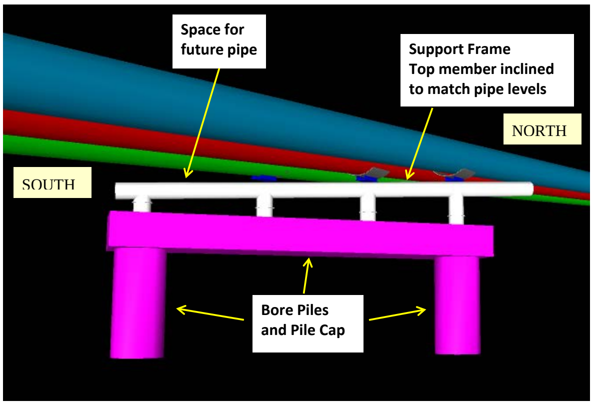

Figure 15: Model of support frame at 45º to pipe axes

11.2 Special Pipe Bracket

In order to ensure that the contact line of the pipe shoe and steel structure remain square to each other, to allow the pipelines to undergo thermal expansion, special brackets (Figures 16, 17) were designed to be used with the special support frames detailed above (Figure 15).

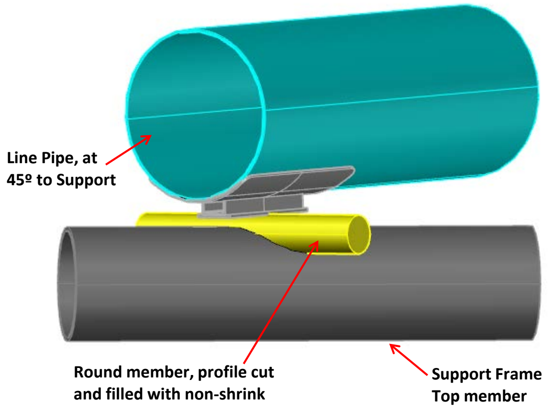

Figure 16: Special Bracket - 3D Design Model

Figure 17: Special Bracket – Field Construction

11.3 Design for temporary Pipe Connection

The temporary pipe connections for Stage-1 used vertical loops to cross-over the adjacent pipe and connect with the outer pipe. The design of the pipelines and supports was suitable for operations both during Stage-1 (temporary) as well as Stage-2 (permanent) pipeline reinstatements.

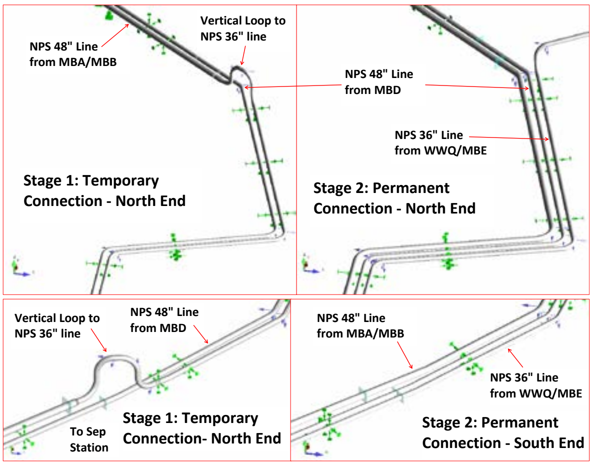

Figure 18: Reinstatement Pipe tie-ins

12. CONSTRUCTION

The pipeline reinstatement works were classified by the Project Owner as a crucial and top priority project. Any delay in project completion would mean high and recurring revenue losses. The project team was focussed on achieving timely completion without compromising safety aspects.

The Project Owner took the lead role to drive the project, coordinated among the major contractors and directly monitored all critical works on site.

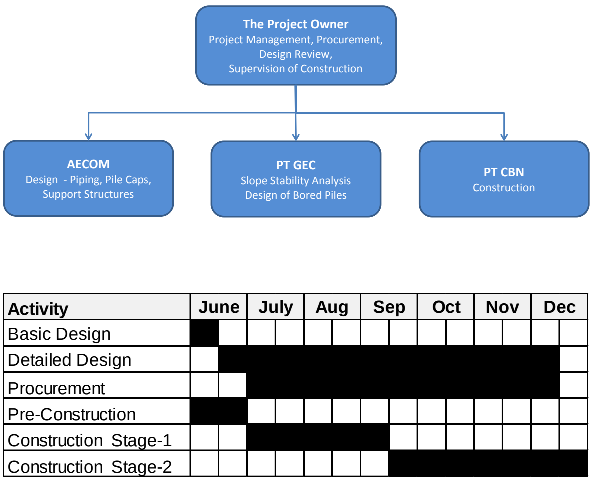

Figure 19: Project Org Chart and Macro Time Schedule

A few of the key strategies adopted and pursued during construction in order to achieve the strict project milestones are as listed in Table 2. Some of the photos during construction are included in Figures 20 to 23.

Table 2. Construction strategic

	Strategic Decision	Example of Actions
1	The Project Owner intensively leads and manages all works.	Twice daily site meetings, before start (morning) and after end (evening) of day's activities, to plan strategy and prepare monitoring schedule for the day's work, resolve daily problem arising from design as well as construction issues etc.
2	Detailed planning and adhering to the project schedule. Parallel design of independent items, such as pipe support frame, bore pile and pile cap etc. Construction of an item was commenced as soon as its design was completed, without waiting for completion of associated items. Thus, design and construction phases could be substantially overlapped	There were 25 pipe support frames, requiring 6 different foundation types, all using bored piles. Parallel activities for fabrication of support frames and construction of support foundations were undertaken, as soon as the design of a particular type was completed.
3	Constantly identify construction activities which were possible to be carried out simultaneously	Weld pipe spools on ground as much possible, before installation of pipe support frames. As a result, when pipe supports were ready, fabricated pipe lengths could be lifted up and placed in position.
4	Prompt and pro-active review of design and speedy decision by the Project Owner regarding design changes, if found unavoidable. It was ensured that drawing approval must not get into the critical path and slow down construction activity on field.	As soon as the design/ drawings were received from AECOM/ GEC, the Project Owner acted immediately to review the same and decide quickly if it could be accepted for construction or needed changes/ modifications. If the design was accepted, it would be issued for construction immediately. If a design change was unavoidable, quick and direct discussion with consultant initiated straightaway to revise the design.
5	Thorough review/ checking of design and drawings, to avoid delays in erection due to errors/ mistakes.	The Project Owner devoted time and efforts to meticulously go through and check information in the pipe data table, support heights etc and ensured that the drawing details conform to field measurements

Figure 20: Lifting of pipe spool onto supports

Figure 21: Fitting vertical loop (in Stage-1)

Figure 22: Construction of support frame LS-15

Figure 23: Before and after Reinstatement Project

13. COMMISSIONING & PLANT START-UP

The pipelines were subjected to in-service leak test, using two-phase fluid from the wells and gradually increasing fluid pressure to the full operating pressure. All observations and inspection results during the in-service test were satisfactory and conformed to the design parameters. Small vibrations were observed in the vertical loops of temporary pipe connections, which were predicted and allowed for in the piping and structural design. The magnitude of such vibrations was measured on site and found to be well within acceptable limits/ safe for operation during temporary piping configuration (i.e., until completion of Stage-2).

Commissioning of the Stage-1 temporary reinstatement pipeline was conducted on September 9th, 2015 and the power station was started up at 85% of full load capacity.

After completing remaining construction work with newly procured materials, commissioning of Stage-2 permanent reinstatement pipelines was conducted on December 31st, 2015. Similar to the Stage-1 commissioning, there was no adverse/ abnormal observation during commissioning of Stage-2 either and the power station was restarted on full capacity without any issue.

14. CONCLUSION

The Project Owner reported satisfaction with the progress and outcome of the reinstatement project, which resulted from close cooperation between the Project Owner and the design and construction teams. The Project Owner was proud of the following achievements during implementation of the project:

- Electricity generation recovered in less than 3 months from the date of the natural disaster;
- Full compliance with national and international codes and regulations were observed in design, installation and testing of the pipelines;
- 600,000 project man-hours achieved without a single Lost Time Incident (LTI);
- The design and construction were completed under budgeted costs;
- Project completion achieved under approved budget.

15. ACKNOWLEDGEMENTS

We thank the Project Owner for all support and permission to publish this work.