New approach for fabrication of penstocks / steel liners for new water conductor system Khopoli by modifying joint design

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ABSTRACT

High tensile quenched and tempered steel, ASTM A517 Gr F or Sumiten 780S, is used for fabrication of penstocks of hydroelectric power plants. In the workshops, submerged arc welding process is used for longitudinal as well as for circumferential joints. When plate thickness is 12-22 mm, usual practice to have single V/double V edge preparation with suitable root face of about 2mm with SMAW root backing. Such joint preparation takes longer for completing welding. Hence joint design was modified having single V from one side and having root face of about 6 mm with zero gap between the plates without SMAW backing. Such modification of the weld design would improve productivity substantially with saving of weld metal. Paper describes successfully implementation of modification of joint design and saving achieved IN terms of man-hours and cost of the deposited weld metals.

INTRODUCTION

Khopoli Penstocks are almost 90 Years old and have outlived their lives. Khopoli Tunnel Project is being taken up as a replacement project for the existing penstock, which besides being more reliable shall also improve efficiency and minimize maintenance cost. The entire stretch traverses the hilly terrain of Western Ghat and crosses the busy Mumbai Pune railway lines and tunnels, both the express and national Highway and inhabited areas of Khandala. The length of tunnel liner / penstock for new water conductor system Khopoli is 3.8 km, comprising of 6000 MT A517 Gr. F and Sumiten 780S steel. The plate thickness is ranging from 12mm to 72mm. The total job is divided in to two stretches called Stretch I and Stretch II.

Stretch I : Comprising of 2650 MT and **7347 meters** welding length. This stretch is awarded to M/s. Skanska Cementation (I) Ltd.

Stretch II : Comprising of 3300 MT and **4848 meters** welding length. This stretch is awarded to M/s. L&T ECC.

Awarding contract of fabrication of penstock

After preparing in details, all requirements and studying capabilities as well as cost angles, the entire job was awarded to the two main contractors as mentioned above.

M/s L&T ECC has two sub contractors (a) M/s Indian Hume Pipe Company Ltd. And (b) M/s P&R. M/s Skanska Cementation (I) Ltd. has one subcontractor that is M/s P.E.S. Engineers. It has been a challenging job for M/s Skanska to complete the entire fabrication of 2650 metric tons. (7347 meter of welding) in the committed stipulated time frame. The essence of the contract was to complete job successfully within the time frame work given in the contract.

Looking at the earlier production figures, M/s Skanska had a stiff task. Table (1) gives information about the average production achieved per month by various contractors for similar type of job i.e. fabrication of penstocks.

Details of the total welding – by Skanska

The welding job given to M/s Skanska had more welding length mainly due to following reasons.

a. Good quantity of steel plates of earlier projects have been used which were procured for lesser diameter of penstock. Hence in order to have required diameter of the penstock additional longitudinal weld joints were made.

b. It was necessary to provide stiffeners for use of plate thickness 12 mm, 15 mm and 16

Table - 1 Comparison Between Monthly Productions at Various Previous Projects

Sl No.	Project	Vendor	Man Power	Average Tonnes / Month	Remarks
1	BHIRA	IHP	130	224	
2	BHIVPURI	IHP/ L& T	71	96	
3	KHOPOLI-Interconnection	IHP	55	19	Interconnection included lot of specials
4	KHOPOLI-Interconnection	ANUP	55	19	
5	KHOPLI –New Water Conductor System	IHP	55	96	
6	KHOPLI –New Water Conductor System	P&R	60	121	
7	KHOPLI –New Water Conductor System	PES	120	154	

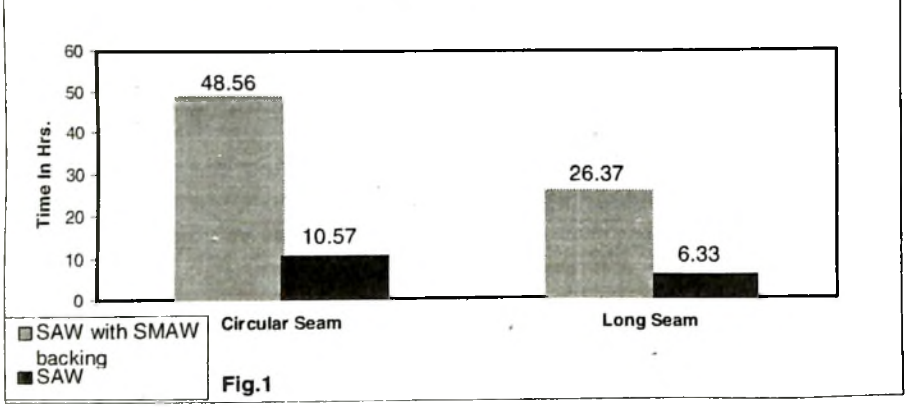

Fig.1

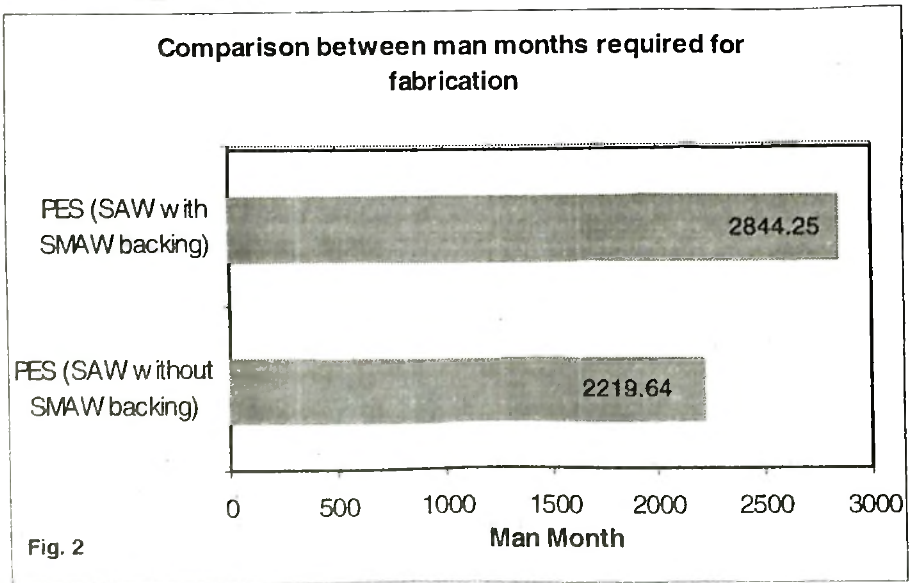

Fig. 2

mm in place of design thickness 18 mm plate. Thus total length of fillet joints due to stiffeners was increased to 10 km. This has resulted in saving of cost and time which otherwise would have been spent in procurement of imported expensive plates.

Improvement in the productivity by modifying joint-design

The usual practice adopted for welding butt joint using SAW process is given in table (2) The butt joint design consists of double V having 2/3 T and 1/3 T and single V having 2 mm root face and gap of about 2 to 3 mm between the plates. Tack welds are deposited using E 7018 – 1 SMAW electrodes and thereafter root is deposited using 3.15 mm diameter from the 2/3 T side, sufficient no of layers are deposited using SAW process.

After completion of the 2/3 T side, root run is gouged out from the other side till, sound weld metal is obtained. Thereafter from the 1/3rd side sufficient no of passes /runs are deposited using SAW process. Since the plate material is high tensile Q&T steel, it is of utmost important to use recommended pre-heat temperature followed by inter pass temperature which should not exceed 130°C till the joint weld is completed.

The current practice used for fabrication is time consuming and thus desired productivity cannot be achieved. Hence in order to achieve higher productivity it was recommended to M/s Skanska to use SAW process without SMAW backing. Modification joint design recommended to M/s Skanska is given in table (2)(Single V having root face of 6 mm with zero root gap). Initially single V side of the joint is to be welded with SAW process. All recommended pre heat temperature and post heat

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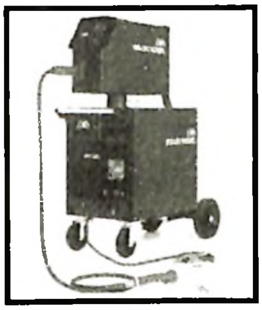

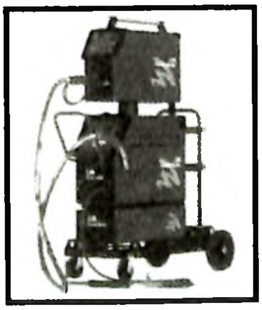

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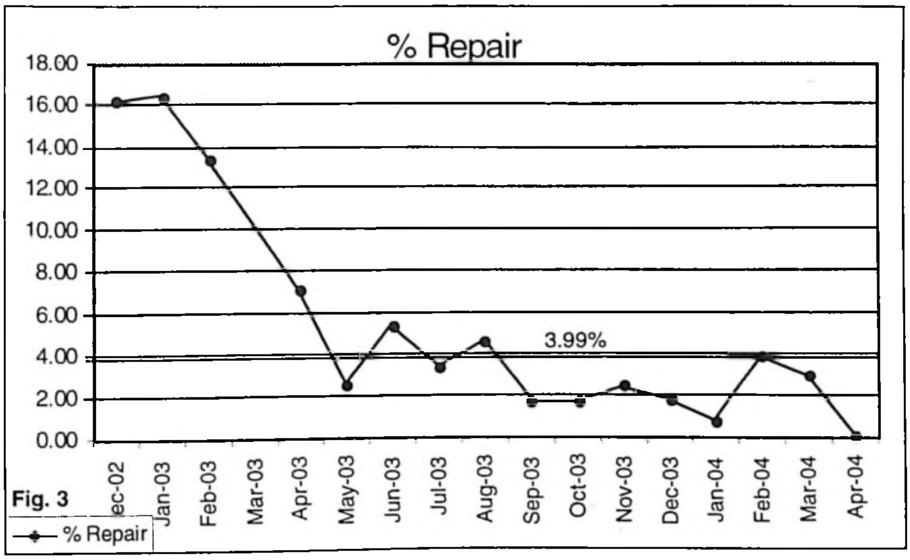


Fig. 3

temperature are to be followed strictly in order to achieve desired strength, toughness and freedom from hydrogen induced cracking

Selection of welding consumables

Only reputed make welding consumables for saw process and SMAW process were allowed to be used. Each batch of welding consumables was tested and approved for its mechanical properties including toughness for SAW, the solid wire used was of the type 3 NiCrMo2.5 and flux used was basic type BB24 procured from Böhler.

Importance of drying welding consumables

As high tensile Q&T steel ASTM A 517 grade F or Sumiten 780 S are susceptible to hydrogen induced cracking, it is necessary that the diffusible hydrogen in the weld metal is lowest (usually not exceeding 2.5ml/100gm of weld metal). Such stringent norms of diffusible hydrogen are achieved by selecting proper consumables and thereafter following recommended drying cycle which is as under.

Recommended drying procedure

a. SMAW electrodes: E11018 electrodes should be dried in calibrated oven at temperature of about 400ºc for 2 hours. The thickness of layers in each compartment of the oven should not exceed two layers of electrodes. The oven should have outlet for escaping of vapor. The rate of heating the oven should not exceed more than 150ºc / hr. Each batch of electrodes should be re baked maximum 3 times; hence total time of baking should not exceed 10 hours.

b. Submerged arc welding flux: The flux should be spread in trays of the drying oven and thickness of the flux layer should not exceed 50mm. The flux should be dried at temperature range of 350°C to 400°C for 2 hours minimum. Above procedure removes almost all moisture from the flux coating of electrodes and the agglomerated flux. Thus deposited weld metal has quite low level of diffusible hydrogen, which is not harmful and does not result in hydrogen induced cracking. Above drying procedure was followed M/s Skanska while fabrication of penstock using SAW process.

Importance of pre heat, inter pass temperature and post weld heat treatment

High tensile Q &T steel type ASTM A 517 grade F of Sumiten 780S are different steels as compared to normal carbon manganese or low alloy steels hence during fabrication pre heat & inter pass temperatures are restricted. The recommended preheat temperature is 65°**C** minimum and inter pass temperature should not exceed 120°C .If inter pass temperature exceeds 120°C then it would result in lowering the strength of the weld joint, especially of heat affected zone. During fabrication of penstock at workshop of M/s SKANSKA temperatures were maintained strictly and the records of it were maintained strictly. After completion of weld joint, it is recommended to give post weld heat treatment of the joint at 250°C for 2 hrs. The post weld heat treatment is given for removing diffusible hydrogen from deposited weld metal in the joint.

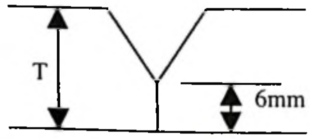
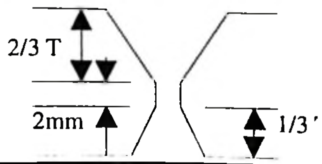
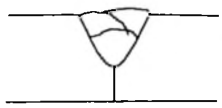
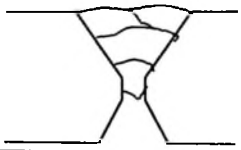
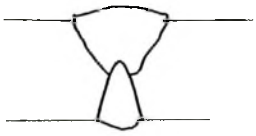
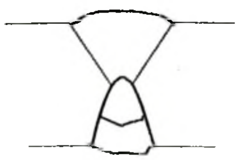
Welding procedure qualification

Initially, welding procedure for SAW process with use of SMAW backing was established in the workshop and details are as given in the table (2). Then welding procedure for SAW process without SMAW backing was established and are as given in table (2)

Inspection and Quality Assurance plan

Quality assurance plan was prepared for each stage of fabrication and was approved. Third party inspection engineers were used for inspection and proper

Table - 2 Comparison Between SAW without SMAW Backing and SAW with SMAW Backing

		SAW without SMAW backing			SAW with SMAW backing			Diagram
Welding Process		SAW			SMAW & SAW			SAW without SMAW backing 
Type		Semi Automatic			Manual & Semi Automatic			
Joint Design		Ref. Fig			Ref. Fig			
Filler Metal		Wire: 3 NiCrMo2.5 Flux: Bholer BB24 (E7018-1 for tacking)			SMAW: 11018-MSAW: same as SAW without SMAW backing (7018-1 for tacking)			SAW with SMAW backing 
Pre heat temp.		65° C minimum			65° C minimum			
Inter pass temp.		120° C maximum			120° C maximum			
Pre heat maintenance		65° C			65° C			
FIRST SIDE WELDING		Process	Amp	Heat Input	Process	Amp	Heat Input	SAW without SMAW backing 
	Tack weld	SMAW 7018-1	90	20 Kj/cm Max.	SMAW 7018-1	80	20 Kj/cm Max.	SAW with SMAW backing 
	Root pass	SAW	650		SMAW 11018-M	145		
	Further Pass	SAW	600		SAW	500-550		
Post heating		Not required, Raise the temperature up to 100°C to maintain preheat 80° minimum			250ºC for 2 hrs.			
Back Chipping		A small grove for guide			Back gouging up to sound metal			
D.P. testing		Not applicable			Applicable			
SECOND SIDE WELDING (All passes)		Process	Amp	Heat Input	Process	Amp	Heat Input	SAW without SMAW backing 
		SAW	750	20Kj/cm max.	SAW	500-530	20Kj/cm max.	
Post Heating		250ºC for 2 hrs			250ºC for 2 hrs			SAW with SMAW backing 

records were maintained. Table (4) gives details of quality assurance plan (QAP).

Time saving achieved due to modifying weld joint design

Reduction of time cycle for circular and long seam is as given in fig 1.

Time saving to the extend of 78% was achieved due to following modifications:

a. Back gouging was eliminated in the SAW Process where as it is essential for SAW process with SMAW backing.

b. Dye penetration test was eliminated because of elimination of back gouging.

c. In SAW process only once PWHT is required where as for SMAW process with SMAW backing PWHT backing is required 2 times, first one after completion of 1st side and second one after completion of 2nd side.

d. Total welding could be completed in one setting without seam was reduced by 78% and long seam time was reduced by about 76%.

Fabrication time management cycle

It was recorded that there has been total saving of total fabrication time by about 28% when SAW process with modified weld joint was used in place of SAW process with SMAW backing. Table (5) gives details of time in hours required for completion of one pipe of 22mm thick plate using SAW process and the second one using SAW and SMAW backing.

M/s PES have completed fabrication in 201 man-hours as compared to 280 man-hours. The comparison of man months for fabrication with and without SMAW backing is as given in figure 2. Scheduled production time frame vis-à-vis actual production achieved in the workshop of M/s. PES Khopoli is as shown in table 6.

It is quite interesting to study scheduled production vis-à-vis actual production achieved at workshop of M/s. PES Khopoli (SKANSKA) following points could be noted.

a. For first six months production was low due to initial development of welding procedure using saw process without SMAW backing. Average production during the first 6

Table - 3 Test results of PQR Comparison Between SAW without SMAW Backing and SAW with SMAW Backing

		SAW without SMAW backing	SAW with SMAW backing
UTS		88.08, 87.87 Kg/mm² – Fracture in Parent Metal	93.06, 92.49 Kg/mm² – Fracture in weld
Bend test		4side bends - Satisfactory	4 side bends – Satisfactory
Impact – Energy absorbed (Weld) at 0°		116.66 Avg.	58.33 Top, 93.33 Middle, 75.00 Bottom
Impact – Lateral expansion (Weld) at 0°		1.25, 1.33, 1.05 mm	0.67, 0.7, 0.92 mm Top 0.93, 1.24, 1.3 mm Middle 1.12, 1.77, 1.1 mm Bottom
Impact - Energy absorbed (HAZ) at 0°		190 Avg.	149 Top, 140.33 Middle, 128 Bottom
Impact – Lateral expansion (HAZ)		2.35, 2.23, 2.20 mm	1.62, 1.61, 1.77 mm Top 1.72, 1.55, 1.9 mm Middle 1.42, 1.2, 1.56 mm Bottom
Vickers Hardness	Weld	294 Top 297 Middle 297 Bottom	327 Top 281 Middle 289 Bottom
	P. Metal Left		287 Top 260 Middle 281 Bottom
	P. Metal Right	270 Top 270 Middle 268 Bottom	270 Top 256 Middle 268 Bottom
	HAZ Left	276 Top 287 Middle 287 Bottom	292 Top 297 Middle 327 Bottom
	HAZ Right		363 Top 283 Middle 314 Bottom
Micro Examination		Satisfactory	Satisfactory

Table - 4 Inspection Stages As Per Approved Quality assurance plan		
Sr. No.	Stage Inspections	Extent of Check
1	Material Identification, Plate Cutting and Edge preparation	100%
2	Welding consumables – Physical Chemical Properties and Hydrogen evaluation	Every Batch
3	Welding qualification	Procedure qualification Each WPS Welders qualification All Welders
4	Rolling, Long Seam fit up and Circular seam fit up	100%
5	Preheating and post heating	100% by electric resistance method
6	Visual Inspection	100% (all butt joints & fillet joints)
7	Magnetic Particle Inspection before Hydro Test.	100% (all butt joints & fillet joints)
8	Radiography testing	100% (all butt joints)
9	Hydro Test	100%
10	Magnetic Particle Inspection after Hydro Test.	100% (all butt joints & fillet joints)
11	Production test coupon	Every 90 meters of long seam welding.
12	Pneumatic test for RF pad	100%

Table - 5 Comparison of Fabrication time Cycle

	SAW with SMAW Backing	SAW without SMAW backing
Thk. Pipe	22 thk	22 thk
Location of Fabrication	IHP	PES
Edge preparation + MPI	10	30
Rolling	8	2
Fitup+ Re rolling	14	10
Long Seam Welding	52	19
NDT long Seam + 48Hrs	56	60
Circular Fit-up	16	5
Circular Welding	64	19
NDT Circular Seam + 48 Hrs.	60	56
TOTAL (Hrs.)	280	201

Table - 6 Comparison between Scheduled and Actual Production at Work Shop

MONTH	Scheduled In MT	Actual In MT
Dec-02	25	0
Jan-03	45	0
Feb-03	62	43
Mar-03	75	133
Apr-03	136	94
May-03	136	98
Jun-03	136	91
Jul-03	78	152
Aug-03	85	276
Sep-03	91	226
Oct-03	106	229
Nov-03	156	234
Dec-03	189	260
Jan-04	185	324
Feb-04	241	180
Mar-04	219	159
Apr-04	146	135
May-04	139	0
Jun-04	120	0
Jul-04	62	0
Aug-04	62	0
Sep-04	74	0
Oct-04	66	0
Average	**114.5**	**154**

months was only 61.33 MT per month.

b. After establishing the new procedure, production increased substantially during the next 11 months when average production was recorded as 206 MT per month.

Saving of weld metal

Because of modification of weld design for SAW process it has been established that there was substantial saving of welding consumables wire and flux quantities required for SAW and SAW with SMAW per meter of welding for 22mm thick plate are given below:

a. Wire and flux quality required for one-meter length of butt joint of SAW weld joint was 1.886 Kg.

b. Wire and flux quality required for one-meter length of butt joint of SAW and SMAW backing was 2.695 Kg.

Thus there was total saving of 30% in the welding consumables when joint design was changed to SAW from SAW plus SMAW backing.

Problems encountered during implementation of modified weld design.

a. Mindsets of welders and welding engineers had to be changed

b. Joint fit-ups are very critical because of zero root gaps. Jigs and fixtures are to be made for fit up.

c. Preheat maintenance during turning of plates for reverse side welding. Increasing weld temperature to 100-120 and using proper lifting tackles solve this problem.

d. Submerged arc welding machine should be capable of producing high current and speed within 1% accuracy. Three machines were rejected because of this.

e. Implementation of storage procedure for flux in recommended manner. It was observed that they were using used flux without proper rebaking

f. Welding parameters are in narrow range. These deviations results in reduction in mechanical strength (production test coupon).

g. During trials, double vee joints had a problem of cracking. Hence single vee joint was adopted up to 22mm thick plates.

h. Initially percentage repair was very high, which was reduced from 16% to 4 % as shown in Fig-3. The overall percentage repair of PES workshop is 3.99%.

CONCLUSIONS

a. Using SAW without SMAW backing welding time cycle is reduced by 78%.

b. This reduces overall fabrication cycle by 30% in comparison with conventional SAW with SMAW backing with required quality.

c. The fabrication of PES is finished 6 months ahead of schedule. 100 personnel are working in PES workshop. Hence the overall saving in terms of man months is 600 man months.

d. Flux and wire consumption reduced by 30% in comparison with conventional SAW with SMAW backing.

e. PES are adopting similar procedures in other sites like Manari Bali (Uttar Kashi).