DERBENDIKHAN HYDROPOWER STATION

REHABILITATION WORKS FOR TURBINE UNIT NO.٢
RUNNER CRACKS REPAIR REPORT

Prepared by

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MAY ٢٠١٣

Derbendikhan Hydro Power Station

DOCUMENT RELEASE INFORMATION

Project name	Derbendikhan hydropower station-rehabilitation works for turbine unit No.٢- Runner cracks repair
Document title	Runner and draft tube inspection and welding procedure unit No.٢ runner repair report.

Contents

EXECUTIVE SUMMARY

Inspection of Unit ٢ Derbendikhan Hydropower station was undertaken during May ٢٠٠٧ as part of ongoing general monitoring of condition. This Unit had no remedial work carried out under the HECEC contract of September to December ١٩٩٩,serious deterioration of the runner in the form of cracking and significant deterioration of the draft tube liner was found.

Remedial action for unit ٢ runner is given special attention in this report with a view to those potentially involved to assess requirements.

Draft tube liner remedial work with respect to effective protective coating application to arrest advanced corrosion and assist with mitigation of cavitation erosion is a pressing requirement for all three units.

Personal Motivation

It is well known that the turbine Unit number two in ٢٠٠٧ in Darbandikhan hydro power s station broke due to cracks and blocking in runner part. Shortly after that several foreign and local companies visited the site and they demanded high cost and more time without giving any guarantee. They asked to buy and change runner part which required more than (٥٠٠٠٠٠٠) five million US $ only to purchase it.

Because I was working in this field for several years, I planned to fix this problem and I visited several times the relevant ministry. After several attempts, my plan was approved and I was appointed to be the supervisor of the project. The turbine was repaired within a short period and it could produce ٨٣ megawatt of electricity which was very beneficial for summertime in that period.

The total cost was only ٢٠٠٠ US $ and the minister himself visited the site and he was very proud of this achievement and he asked to elevate my rank. The turbine is now working very well after repairing since ٢٠٠٧ till now. It is working more than (١٣٣٠٣) hours. It proves that reparation was done provisionally scientifically and we could save about (٧٠٠٠٠٠٠) seven million US $.

This achievement was highly appreciated by the people and media and even by the foreign companies.

Enginner

١. INTRODUCTION

١.١ BACKGROUND INFORMATION

A brief history of the power station is:-

- Mitsubishi contract was let in 1979.
- Workcommenced in1980.
- Contract completed 1985.
- Iraq/Iran war 1980 to 1988.
- 1994 132kv line to Sulaymaniah Re-established.
- 1996 Unit 2 Repaired.

A contract was let with HECEC by UNDP for draft tube and Runner repairs to all Units and work was carried out during the period September 1999.because the extent of work required was much greater than had been assessed or allowed for in the contract, works could not continue beyond that time.

١.٢ CURRENT INFORMATION

As inspection of Unit ٢ was conducted late February ٢٠٠٢ and it was noticed that there were cracks evident in the Runner that had developed significantly and that there were new cracks as well. Further checking with dye penetrant was instigated with one additional crack being found and the details taken by photograph and measurement. A total of ٤ cracks have been identified.

Early inspection details have been circulated for opinion regarding appropriate repair of the runner to return it to satisfactory condition. Opinion from persons experienced in this work, includes Malcolm Scott, Roger Hurt of Alston and Frank McKnight of UNDP (part author of this report) are found in appendix ٢.

Draft tube defects in the area immediately below the runner were inspected also, but with less attention to these than the condition of the runner.

Because of the findings associated with unit ٢, inspections of unit ١ and ٣ were arranged, particularly to inspect for cracking of the runners. No cracking of the runners of those two units was found. Some liner deterioration has occurred, but is considered to be progressive without immediate threat to operation compared to the crack propagation and associated approach of catastrophic failure of the unit ٢ Runner.

١.٣ Component Materials

The mechanical data book for the power station (by Mitsubishi) provides a description of the material of the runner as stainless steel casting. (See appendix ١).

١.٤ Running hours comparison chart

UNIT N٠.	YEAR	RUNNING HOURS	TOTALS	COMMENTS
٢	١٩٩٧			Put into operation on ١/٥/١٩٩٧
٢	٢٠٠٠	١٢٥٠٦		Inspection carried out on ٢/٧/٢٠٠٠
٢	٢٠٠٠	١٠٣٢	١٣٥٣٨	Inspection carried out on ٣١/١٠/٢٠٠٠
٢	٢٠٠٢	١٧٨٥	١٥٣٢٣	Inspection carried out on ١٧/٢/٢٠٠٢

٢. UNITN٠.٢

On ١٧ February ٢٠٠٢ as inspection was carried out on unit # ٢ draft tube and runner by (UNDP) and (SEA) staff along with a representative from the SalahadinUniversity.

Several cracks were observed in the turbine runner.

A second inspection was carried out on ٢٦ February for a more detailed inspection and photographs were taken of the large cracks in the runner, plus the cavitations damage to the draft tube liner and air inlet pipe work.

UNDP staff carried out a further inspection on ١٠ March ٢٠٠٢ to instruct the local staff on the use of dye penetrates on the runner to accurately measure the length of the cracks.

٢.١ Runner (Unit ٢)

Dye penetrate non-destructive testing employed to better establish the full extent of cracking found during the earlier inspections and to ensure as far as possible that there were no further cracks in any part of the runner.

Cavitationdamage was also carefully inspected and documented.

٢.٢ RUNNER CRACKS (UNIT ٢)

I summaries below the cracks as I understand from the report and photos:

Significant cracking as inspected is reported below blade crack data.

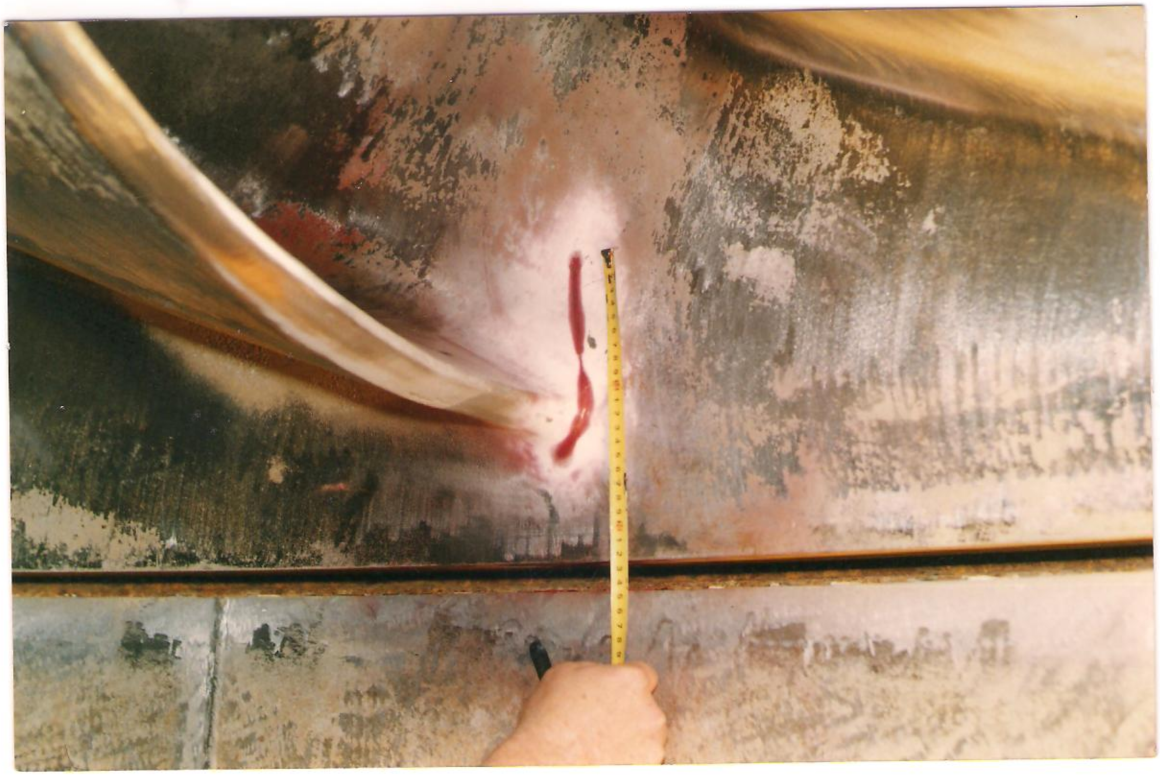
BLADE	LOCATION	STRAIGHT LENGTH	STRING LINE LENGTH (crack followed with loose string).
No ٢ and skirt (Ref plate ١)	Lower skirt	٢٥٨ mm	٢٧٨ mm
Adjacent no ١٢ (ref plate ٢)	Nose cone	٣٨٦ mm	٣٨٦mm outside nose cone.

No ١٣ (ref plate ٣)	Nose cone end on nose cone 'side'.	٧٤٠mm followed by ١٨٠mm.	٧٤٠mmtotal (٢٥٦mm along ١٨٠mm 'line').
No ١٣ (ref plate ٤)	Nose cone end on nose cone 'side'.		٧٤٠mmtotal (١٧٥mm along ١٨٠mm 'line').
No ١٠ (ref plate ٥)	Nose cone end d/s edge.	٨٤mm wicket gate side. ٦٠mm nose cone side.	١٨٠mm total.

Table ٢.١.١ blade crack data

٢.٣ Blade ٢ and skirt

The crack is at the trailing edge of the blade at the blade to the lowerskirt transition (welded joint and then vertically up into the skirt well away from the joint, straight line length ٢٧٨mm.it may well be that the crack is full depth, but this would need to be determined by ultrasonic inspection technique or assessed during grinding apart of a repair procedure.



Blade ٢ and skirt (plate ١)

٢.٤ Nose cone adjacent blade ١٣

A large crack was clearly visible on the outside of the cone vertically beyond blade No ١٣in the direction of blade No ١٢ , this crack was also on the inside of the nose cone , indicating full depth cracking over the smaller length.

The crack is longer on the inside of the nose cone at ٧٤٠mm compared to on the outside at ٢٥٦mm .It is outside the transition of the welded joint between the blade and the nose cone and extends well above and well below this transition. It is not known where the vertical nose cone joint is (having been manufactured from plate).

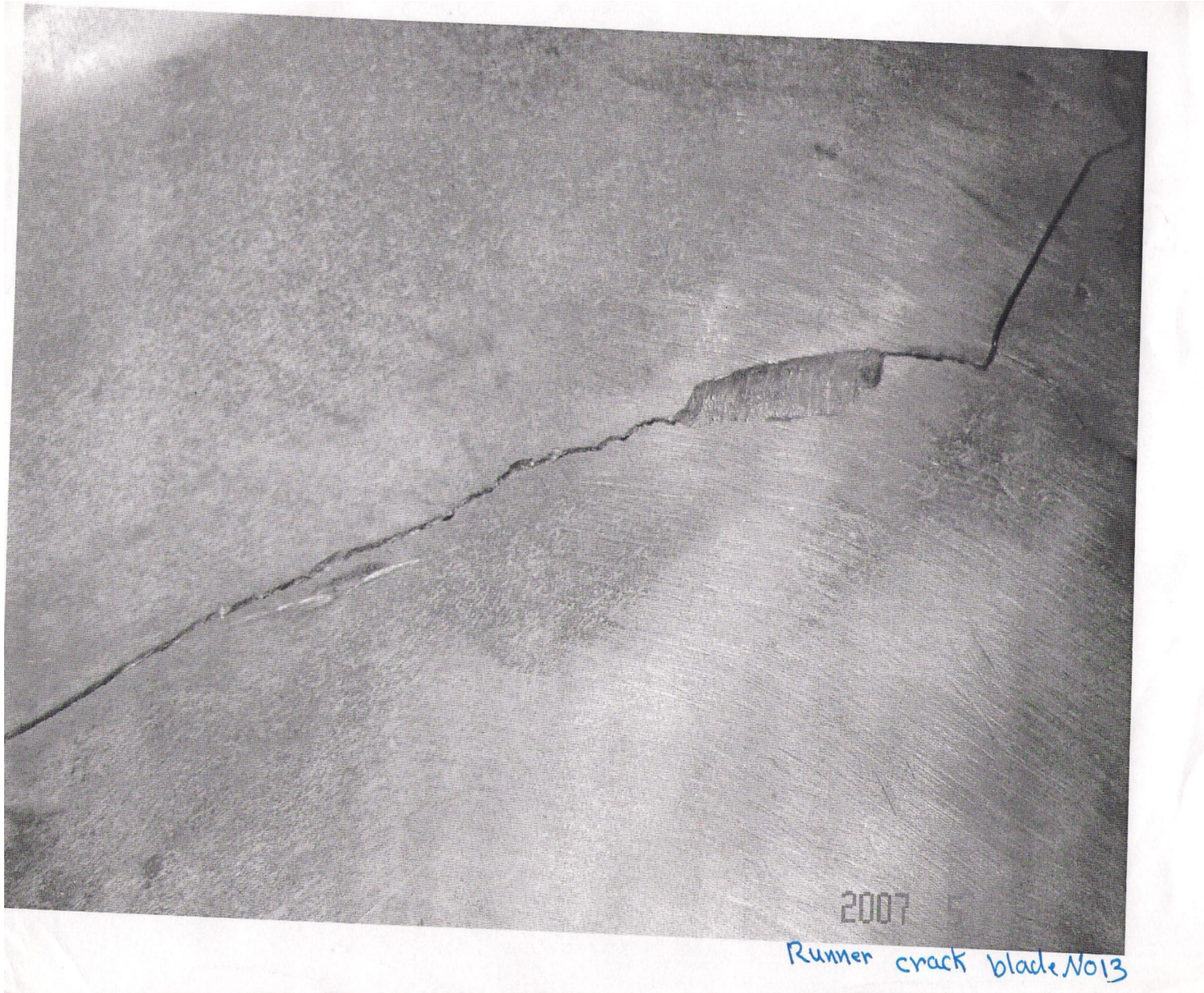
Outside nose cone adj. blade ١٢ (plate ٢)

٢.٥ Blade ١٣

Horizontally large crack was clearly visible in blade no ١٣ between the trailing edge and a point well towards midway back in to the blade, horizontally in a zigzag manner (veepattem) and near the top of the blade, (see plate ٣a and plate ٤).

This crack has a total actual length of ٦٠٥mm (followed with loose string) on the nose cone side (see plate ٤). The sharp change in direction is a significant phenomenon as if two separate cracks have been propagating at right angles and towards one another and have met. It is clearly trailing off towards the inlet edge the blade and the indistinct curve appears to be surficial rather than deep until the very end-not seen on the other side until this point. The camera was able to pick up the end mark but there was insufficient room to examine this by direct eyesight due to the limited space in the area.

Blade ١٣ on nose cone side (plate ٣)



Blade No.١٣ crack (plate٤)

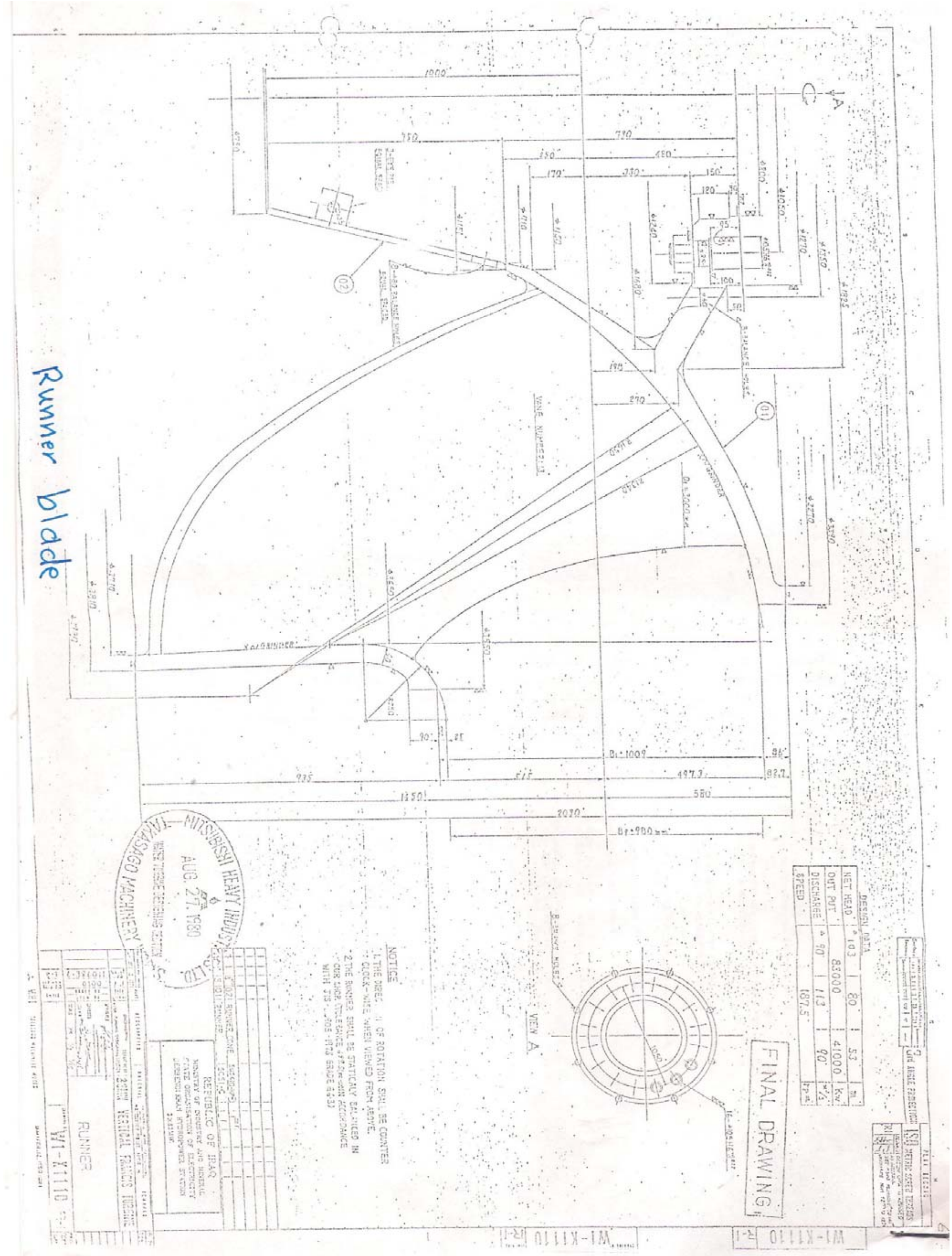
٢.٦ Blade ١٠

This is shown in the following photos (plate ٥).

The crack extends right around the trailing edge near to the nose cone joint. It continues ٨٤mm from the trailing edge of the blade on the wicket gate side and ٦٠mm from the trailing edge on the nose cone side, with a total length of ١٨٠mm (followed with loose string).

There is excess developer away from the crack which gives the impression of discontinuities in the surface. These do not exist.

Blade No ١٠ crack (plate٥)


Runner blade
FINAL DRAWING
VIEW A
NOTICE
RUNNER
WI-K1110

٣. Runner Cavitation Damage (unit ٢)

The trailing edges of the runner blades themselves exhibit heavy cavitation erosion covering areas indicated in table ٢.١.٢

Blade No	Lower Radius	Blade Face	Trailing Edge
١	٤٥cm*٢٦cm	٤٢cm*١٦cm	٢٨cm*٩cm
٢	٥٧cm*٣٨cm	١٩cm*٨cm	٢٢cm*١١cm
٣	٦٠cm*٢٧cm	٣٧cm*١٩cm	٢٤cm*٨cm
٤	٣٩cm*٨ cm	٣٧cm*١٢cm	١٩cm*٩cm
٥	٤٥cm*٣٩cm	٢٨cm*٩cm	٢٨cm*٩cm
٦	٥٢cm*١٤cm	٤٨cm*١٩cm	٢٥cm*١٤cm
٧	٣٨cm*٢٥cm	٥٢cm١٩cm	٢٥cm*١٩cm
٨	٥٣cm*٣٥cm	٤٢cm*٢٢cm	٣١cm*٩cm
٩	٦٨cm*٣٩cm	٣٢cm*٢١cm	٢٣cm*١٢cm
١٠	٥٠cm*١٩cm	٤٥cm*١٢cm	٣٤cm*٢٥cm
١١	٤٦cm*٣٠cm	٣٥cm*٢٢cm	٣٩cm*٢١cm
١٢	٥٠cm*٣٢cm	٤١cm*١٦cm	٣٦cm*٢١cm
١٣	٤٥cm*٣٠cm	٤٥cm*١٢cm	٢٤cm*١٥cm

Table ٢.١.٢ cavitations erosion- unit ٢ runner blades trailing edges the '٠' entries indicate areas where heave cavitation damage covers mostly the lower radius and carries through to the blade face as a whole.

٣.١ Unit ٢ Runner Condition Assessment

The damage and defects that have been described give rise to serious doubts regarding the success of any repair action that may be contemplated.

Running hours are significantly less than those for any other of the turbine units, ٣٠%of the hours of unit ١ and ٤٥% of the hours of unit ٣, yet the degree of cracking is extreme by comparison with the other two. During the contract for repair of the draft runners and tubes when work was undertaken on unit ١ and ٣, only ١ crack was evident in the runner of each and in need of repair.

During previous inspections of the No.٢ unit runner no cracks have been found. Whatever the circumstances it is unlikely that all cracks have been missed previously. This indicates that at least some of the cracks are propagatingatarate such that further operation of this unit would put it at high risk of failure at an unknown time and likely to be accompanied with catastrophic damage to other turbine components.

The apparent rapid onset of cracking also raises serious questions about the metallurgical state of the runner. This has been implied by Malcolm Scott who, in his opinion included in appendix ٢, recommends full radiographic or ultrasonic examination of the runner to further check the integrity of the runner. Deep and sizable inclusions in the casting may be weakening it and/or causing work-hardening by flexure outside design limits. Also, it may be that the annealing carried out was not sufficient in this case and residual stresses are having effect in the manner observed.

Whatever the exact cause, it is not possible to determine it by further visual determination. Ultrasonic or radiographic and/or sample testing is required to gain further knowledge of the runner condition. as ultrasonic or radiographic equipment are not readily available, it is considered that samples testing would be the best first choice. Metallographic testing to determine the state of the runner material and the presence of inclusions or porosity at failure sites should therefore be undertaken for the next stage of condition assessment towards estimation of the extent of further service life.

At the present time, a summary statement is that there is no indication that the runner is safe for any further use until measure are taken to improve its condition by a measurable degree.

٤ Repair

٤.١ Cracking

Weld repairs were carried out in-situ on unit No.٢.including (٤) cracks repair that has not failed after a further ٦٠٠٠ hours. The potential for success by weld repair is therefore established, contingent upon the material. A strategy of structural (minimal) repair (dealing with cracks only) or more extensive involving some cavitations damage could then be determined.

PreparatoryGrinding.	To a depth and width such as is shown in the sketch of the weld below-to be varied according to depth of crack and access on the reverse side. Full depth cracks in blades would have half depth grinding initially, with all remaining depth of crack removed and welded from the reverse side.
Preheating & temperature maintenance.	٧٠ C to be achieved and maintained in the draft tube Local heating in the ground area to ١٢٠ C and then maintaining ١٠٠ C base metal temperature all around the crack area throughout the welding procedure
Welding requirements.	weld runs All Build up run: run ١ to ٨ with Gr ٣٠٩ , ٣.٢ dia Capping runs: run ٩ to ١٣ with ٢٢٠٥ , ٣.٢ dia Dye penetrate checks , Before welding ,during build up and after completion Peen between each layer of weld Back grinding as necessary before proceeding with further welding
Post weld heating	Maintaining temperature in the base metal of ١٠٠ C for a specified period according to weld size after the

	completion of welding .Then allowing air cooling with draft tube temperature still maintained
Finish grinding and polishing.	Grinding to profile with any finish welding using TIG with ٢٢٠٥ wire ,but again using preheating temperature maintenance and post weld heating as required

Table ٢.٣.١ typical crack repair technique

(To be custom modified for each defect in unit ٢ runners)

It should be noted that the logistics of carrying out repairs in this way are very demanding upon the welding .Each crack repair must continue with the heating levels maintained .It is therefore necessary to have several (٤ recommended) certified welders to operate in turn with one another and welders assistants (٤ recommended) to operate in the same cycle for the heating maintenance and testing procedures .Between welding temperature in the draft tube must be maintained and cooling down of the base metal temperature according to the above requirements .

٢.٤ Cavitations Damage

Cavitations damage repair is considered separated as it does not constitute an immediate structural threat to the runner and the damage in itself does not prevent the runner's availability for standby use in the event of an emergency.

A typical repair methodology, as defined for the previous repairs to the Unit N٠ ٢ runners.

Task	REQUIREMENTS
Initial	Dimensional check and recording of blade and critical runner dimensions,(center distances of blades, gaps between runner wear ring and SS top liner).
Manufacture of templates of blade profiles.	Manufacture sheet from ١.٦mm steel with finished profile gauged from a blade chosen to be least damaged. Several to be made to cover profile changes along the damaged area.
Preparation for welding	Grinding to ensure a sound base for welding with disks suited to this requirement (Pferd-inox) have been previously nominated All electrodes to be free of moisture and dried out at ٣٠٠ C for ٢ hour prior to use. Preheating of draft tube to ٧٠c. Preheat base metal to ١٢٠c.
Welding general	Sequential welding to minimize heat concentration in one area of runner. Preferably, opposite runner blades to be repaired in turn to minimize distortion effects. Initial run to be with AWSER٣٠٩L electrodes. Initial run to be covered with cavitec. (see list of materials available ex UNDP warehouse re both consumables)[١]

[١]

Welding-technique	Vertical up technique. Maintain base metal temperature of ١٠٠c.
Testing	Dye penetrates testing after welding –back grinding and repairing as necessary according to test results.
Finishing	Proof grind and then NDT. Finish grind to profile and polish with emery wheel. Final NDT. Dimensional check of blades and runner critical dimensions-compare to those at start and take remedial action it necessary

Cavitations Damage Repair – Typical for Runner Blades

As with the crack repairs, it should be noted that the logistics of carrying out this work are very demanding upon the welding .Each repair must continue with the heating levels maintained .it is therefore necessary to have several (٤ recommended) certified welders to operate in turn with one another and welders assistants (٤ recommended) to operate in the same cycle for the heating maintenance and testing procedures .Any breaks would still enquire draft tube temperature maintenance.

٥ Draft Tube Liner (UnitNo.٢)

٥.١ Condition

The top stainless steel section of the draft tube liner appears to be in good condition but the carbon steel below it is in poor overall condition.

The worst part is near the first leg of the air admission pipe No.١ (see plate ١١) ,at the right of the entrance door. The heavy cavitations erosion at the bottom left has holed the plate and cavitations are now eroding the concrete in this area very deeply.

Heavy cavitation damage-liner holed in the wake of air admission pipe (plate ٦)

The transition area between the stainless steel and carbon steel sections is in poor condition (see plate ١٢) and exhibits cavitationerosion by small holes in areas through to the concrete, right around the draft tube to approximately ١١cm below the weld join.

In this area, the liner plate appears to be about ٢mm thick which is considered inadequate for the required service. The implication is that this section of draft tube liner was no more than ٢mm thick when installed as has been suggested on previous occasions for unit ١ during its repair under the HECEC contract.

The other two legs of the air admission pipe works.

Draft tube repairing (plate ٧)

٥.٢ Repair Requirements

All repair requirements have been nominated at earlier dates. Significantly increased deterioration now should be undertaken as soon as possible.

• Repair by welding in new sections of plate, minimum, in the short term, perhaps including stainless steel overlays to better resist the cavitation prone areas.

• Establish adequate anchorage of the liner.

• Rerouting of voids behind the liner and the area (s) that have been affected by cavitation/water ingress.

• Application of a proven protective coating to manufacturer's specification including abrasive blast cleaning and coating build under correct application condition is also required as soon as possible.

٦ APPENDIX ١ MITSUBISHI DATA

٦.١ MATERIALS

The Mechanical Data book for the power station (byMitsubishi) gives the following information under Material List:

Name of Component	Material	Material Specification	Equivalent ASTM	Equivalent BS
Runner and Guide Vane	Stainless steel casting	JIS-G٠٥١٢١ Grade ١ (SCS١)Modify	A-٢٩٦ Grade CA-١٥	١٦٣٠ Grade A
Facing plate, Wearing Ring Turbine shaft Sleeve, Runner Cons and upper Part of Draft Tube Liner	Stainless steel plate	JIS-G-٤٣٠٤ (SUS٤١٠)	A-١٧٦ Type ٤١٠	١٤٤٩ (En ٥٦A)
Draft Tube Liner, Pit Liner and Storage Tank	steel plate	JIS-G٣١٠١ SS٤١	A٢٨٣ Grade B	١٥ Grade ١

٧ Materials Performanceand Chemical Analysis

Under Appendix ١ in the Mechanical Data book, the following tabulated information is given:

Mechanical Properties	Material		
	SCS١-C	A٢٩٦ Grade CA-١٥	B.S.١٦٣٠ Gr A
Tensile strength min ksi (kg/mm٢)	٩٢.٤ (٦٥.٠)		
Yield Point min ksi (kg/mm٢)	٧١.١ (٥٠.٠)		
Elongation in ٢ inches min	١٥%		
Reduction of area , min	-		
Brineil Hardness Number	Min ٢٠٠		
Carbon , Max %	٠.١٥	٠.١٥	٠.١٥
Silicon , Max %	١.٥	١.٥	١.٠٠
Manganese ,max %	١.٠٠	١.٠٠	١.٠٠
Phosphorus, Max %	٠.٠٥	٠.٠٤ (a)	-
Sulfur,Max %	٠.٠٤	٠.٠٤ (a)	-
Chromium,%	١١.٥ – ١٢.٧	١١.٥ – ١٤.٠	١١.٥ – ١٣.٥
Nickel,Max %	٠.٨ – ١.٢	١.٠٠	١.٠٠
Molybdenum,Max %	-	٠.٥ (a)	-

(a) Chemical analysis is not normally required for the elements phosphorus ,sulfur and molybdenum, but if they are present in amounts over those stated they may be cause for rejection .xaCFCccvc a

٨ Welding Procedure – Unit No.٢ Runner Repair

The large crack in the runner could be repaired by the following standard procedures.

Clean and Dye penetrate check for crack

Profile shape of blade (profile comb or template)

Drill hole at ends of crack to prevent further travelling

Grind half way through area of crack

Heat draft tube to ٧٠ C

Local heat ground area to ١٢٠ C

Weld ground area with appropriate stainless steel material until raised above normal blade area

Grind back to flush with normal blade area (using profile comb or template as guide).

Polish area smooth with emery wheels.

All the activities above can be carried out in conjunction with each other; the following steps would be required to complete the repairs.

The above repairs would safeguard the runner from any father damage to these areas.

References

١-My working experiences in Darbandikhan power station especially (Runner and Draft tube)

٢-Working experience with HECEC an Australian company in ١٩٩٩ which expert in treatment of cavitation

٣-Technical specification documents which prepared by Mitsubishi for Darbandikhan power station

٤-UNDP Engineers Report

A-Malcolm Scott

B- Frank McKnight

C- Murray Shinkfield