ANALYSIS OF THE FAILURE
OF THE
INDIAN SCHOOL BRIDGE
Agua Fria River

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BY

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It is my conclusion that the effects of the meander pattern which was established independently of the conditions downstream of Indian School Bridge on Agua Fria caused localized scour which resulted in the failure of the bridge piers. I also believe that this failure would have occured with or without the restriction of flow caused by gravel operations downstream of the bridge.

1. The general meandering pattern of the main flow within the channel was determined by factors independent of the conditions at Indian School Bridge. Note that the elevation of the channel bottom is more than 10ft. above the high water at the bridge. (See Fig. 1.) Therefore, it could be said that the conditions at the bridge had little influence on the meander pattern established at a higher elevation and more than a mile upstream of the bridge.

2. Also, by observing the flood photo (Fig. 2.) it can be seen how the majority of the flow was concentrated in the meanders within the limits of the main channel. The wave action shows how the majority of scour & flow was occuring within outline of this meander pattern.

3. As the flow increased the width of the meander pattern increased and also shifted down stream. (See Fig. 2, 3-A, 3-B, & 3-C.) These are natural results of this type increased flow. (See Fig. 5-C.)

4. As the meander width (amplitude) and increased period shifted downstream, the flow was caught in a sharp bend at the east approach to the bridge. (See Fig. 4 .) This caused an abrupt change in direction of flow causing an excessive amount of flow to be directed at a high velocity toward the second, third & fourth piers ~~east~~ NE of the abutment. There was attack at a lesser angle on the other piers.

PRELIMINARY

5. From laboratory tests in alluvial channels it can be concluded that maximum velocities and scour depths occur in the outside and near the end of curves. (See Fig. 5-A, through F.)

6. Field observations on Agua Fria near McDowell show that extreme scour can take place at a bend where large changes in direction take place in relatively short distances. (See Fig. 7 & 8 .) Notice the depth of scour in the bend (Fig. 8) which was observed after the storm. It was approximately 15ft. below the approaching channel bed. Also notice the cutting which went on at the turn.

7. Therefore, it can be said that even before the flow reached the diversion caused by the bridge piers, it was scouring the channel bed to depth with high velocities and concentrated flows. (See red area on Fig. 9 .) If the storm would have continued, it would probably have taken out the east approach to the bridge.

8. Shortly after the flow left this bend at the east abutment, it was caught mainly by the second, third & fourth piers to the west of the abutment. (See Fig. 10.) Note the turbulence at the approach to the bridge and visualization of turbulence underwater. (Fig. 11.)

9. Equations have also been developed in model studies which will predict scour at piers where angle of attack is the only factor in scour, (See App 2, P-82 to 90.) but, these lose credability when applied to conditions existing at the time of the Indian School Bridge failure. Since the approach depth is difficult to estimate because of the scour taking place as the result of the change in direction of flow just upstream of the piers. Also applications of these theories leaves room for some refinement. (See App. 2 P-94.)

10. For the sake of this discussion, conservative values for important variables were chosen to calculate theoretical scour depth. This was done so that it could be said that minimum theoretical scour depths were still deep enough to cause bridge failure. (See Fig. 12), calculations which shows a scour depth of 5ft below observed scour depth. See Fig. 13-A.)

11. The importance of the angle of attack in scour analysis can not be underestimated. (See Fig. 13-B.) Also, note on Fig. 13-C the angles of attack observed at the Indian School Bridge.

12. Also See Fig. 13-D, which shows an actual measured cross-section during a flow on the Hassayampa River where the bridge pier was under an angle of attack by relatively small flows. Note the extent of the measured scour.

13. Therefore, it could logically be concluded that the failure would have taken place because of the effect of angle of attack alone.

14. Remember on top of this scour from the angle of attack, scour was taking place upstream of the piers because of the change in flow direction mentioned in 7 above.

15. Since the combined effect of a sharp bend upstream of piers under a large angle of attack has not been studied in models or elsewhere, we can only conclude that the effects of the scour conditions added together only makes conditions contributing to a failure worse.

16. Note how much scour actually resulted from Fig. 13A, showing the second pier west which shows how the north part of it sunk about 5ft. into the scour hole.

17. Also, note how the north part of the third pier has fallen. (Fig. 9 & 14 .) This pier probably took the brunt of the diverted flow which hit it in the latter portions of the hydrograph at an extreme angle of attack. The south half of the pier also dropped 5ft. into a scour hole which developed. (See Fig. 15 pictures under bridge.

18. From Fig. 16, blue line, showing the depth at which hard ground was encountered, you can see how much the bottom of the channel was scoured. This occured in a relatively small portion of the bridge where a large portion of the flow was concentrated with relatively large turbulence. See Fig. 3-A, which shows turbulence down stream of the bridge, and also shows there was an angle of attack on other piers. Therefore, scour depth could have been close to foundations at a number of piers.

19. Now back to the meandering problem. Many people have tried to describe this phenomenon by equations, one of which is shown in App. No. 1, but because of limited field data, it has been difficult to develop reliable equations for alluvial streams similar to Agua Fria, at Indian School. One conclusion can be made and that is that there is a relationship which exists, and it can be said that this natural cycle was interupted by the east abutment of the bridge, causing a great deal of damage.

20. Note the vegetation up and downstream of the bridge after the storm, (See Fig. 3-C), which shows that in the majority of the channel, down-cutting was not a major problem. It seemed to be localized in a close proximity to the bridge. It can be seen on Fig. 4. The same down cutting could have occurred in part of the channel in the restricted area downstream of the bridge.

21. Now addressing the gravel operation problem downstream of the bridge. It of course can be argued that the flow was concentrated in a narrow cross-section by the gravel operations downstream of the bridge and that this caused scour which traveled upstream under the piers. My argument to this is that it may have contributed in a relatively minor way with additional scour. The major scour was relatively localized mainly at three piers, and was mainly from local causes as I have described. It could be concluded that if the flow had been lined up with the piers (with a small angle of attack) and evenly distributed through half the bridge, even with the gravel operation the bridge would have easily survived.

It is also my conclusion that the effects of the meander pattern which was established independently of the conditions downstream of Indian School Bridge on the Agua Fria resulted in the failure of the bridge piers. Through research of other studies and an indepth search for the facts in this case, I believe that this failure would have occured with or without the restriction of flow caused by gravel operations downstream of the bridge. (App. 2, p-1.)

PRELIMINARY

RECORDED FLOOD FLOWS IN CFS

DATE	PHOTO DATE	AGUA FRIA RIVER			NEW RIVER	
		WADDELL DAM 25 MI. UPSTREAM	EL MIRAGE 8 MI. UPSTREAM	AVONDALE 4 MI. DOWNSTREAM	BELL ROAD 10 MI. UPSTREAM	GLENDALE AVE. 3 MI. UPSTREAM
	01/03/58					
12/25/59				4700(N.R.)		5500(1960)c)
08/ /63				63(N.R.)		690(1963)c)
09/ /63				700		
	01/21/64					
07/30/64			2500			7000(1964)c)
08/01/64				3000(N.R.)		
10/16/64			500			1100(1965)c)
04/04/65				460		
12/23/65				800		
08/10/66			2900			3000(1966)c)
12/19/67			2520		14,600	19,800
12/20/67				20,000(N.R.)		
09/13/69			600			
	01/29/70					
09/05/70			5000			
09/06/70				20,600(N.R.)		19,200
08/ /71			250			7000(1971)c)
08/21/71				8200(N.R.)		
06/ /72			10			
07/17/72				5180(N.R.)		6300(1972)c)
10/07/72			20	5000(N.R.)	2590	8650(1973)c)
08/05/74			460			775(1974)c)
11/02/74			50			
11/02/74					257	
	01/02/76					
02/09/76					2280	
	02/25/76					
	12/28/76					
03/02/78			9870	13,100[b)] (N.R.)	12,500	
03/05/78		16,000				
03/ /78		45,800				
	12/14/78					
12/19/78		59,900[b)]	58,400[a)]	30,000[b)] (A.R.)	6230	
01/17/79		25,800[b)]		24,800[b)] (A.R.)		
	12/15/79					
02/15/80		44,000[b)]		31,000[b)] (A.R.)		
02/17/80		11,000[b)]		7,000[b)] (A.R.)		
02/20/80		66,600[b)]	41,800	44,000[b)] (A.R.)		8700
	02/28/80					
	12/15/80					

a) Poorly rated

b) Hydrograph available

c) Maximum flow for that Water Year.

SCOUR ANAYLSIS

INDIAN SCHOOL ROAD BRIDGE

CAUSES OF SCOUR

NATURAL: Meandering or Lateral Migration
Angle of Attack

MAN-MADE: Headcutting Pits 1,2,3
Dike Constriction
Upstream Gravel Operation Pit 4
Dam Releases - Magnitude and Volume of flood
Location of the East Abutment of Bridge
Skewness of piers or type of piers

AGUA FRIA RIVER

BED PROFILES

Stream stationing are in rivermiles

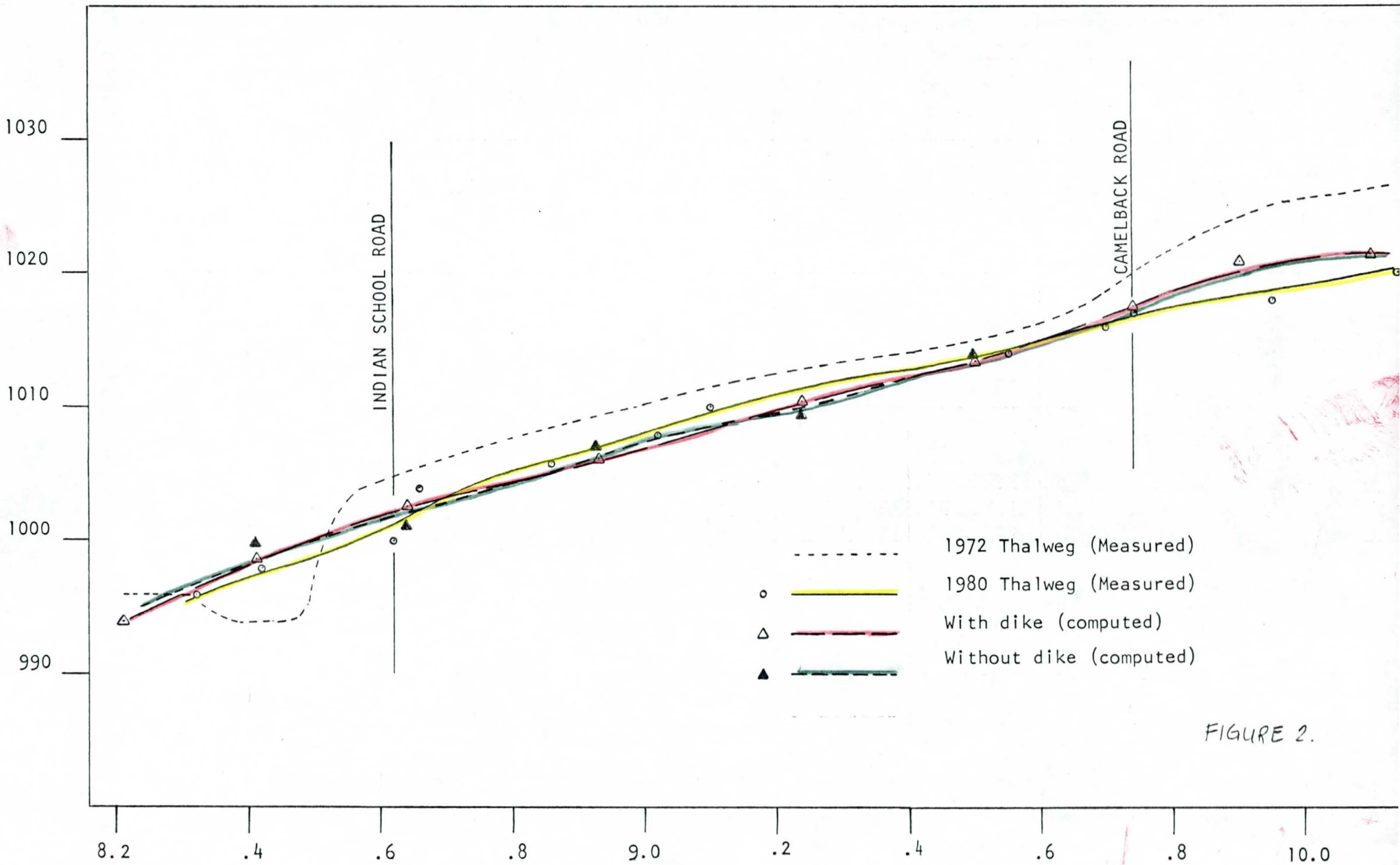


FIGURE 2.

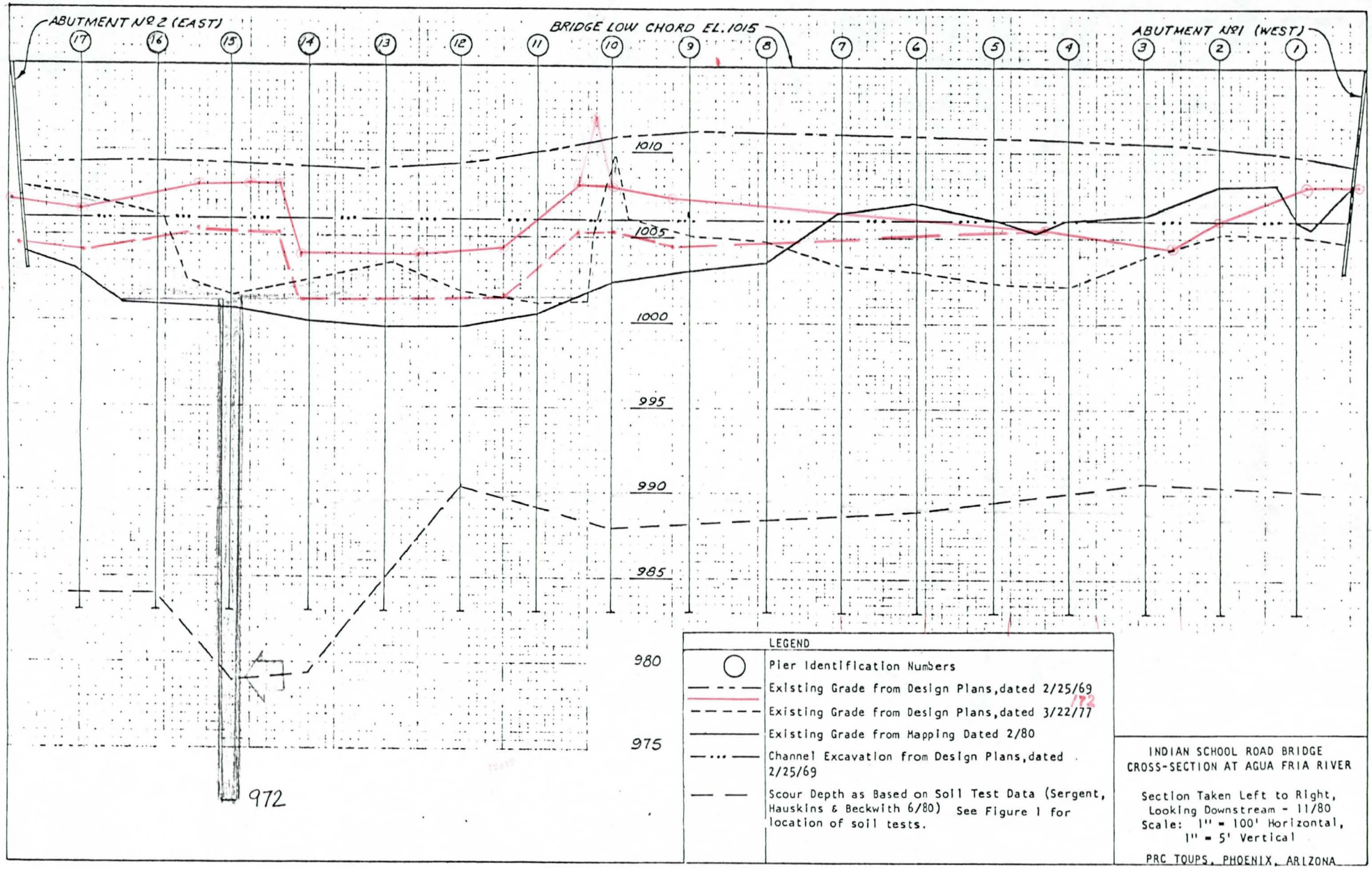
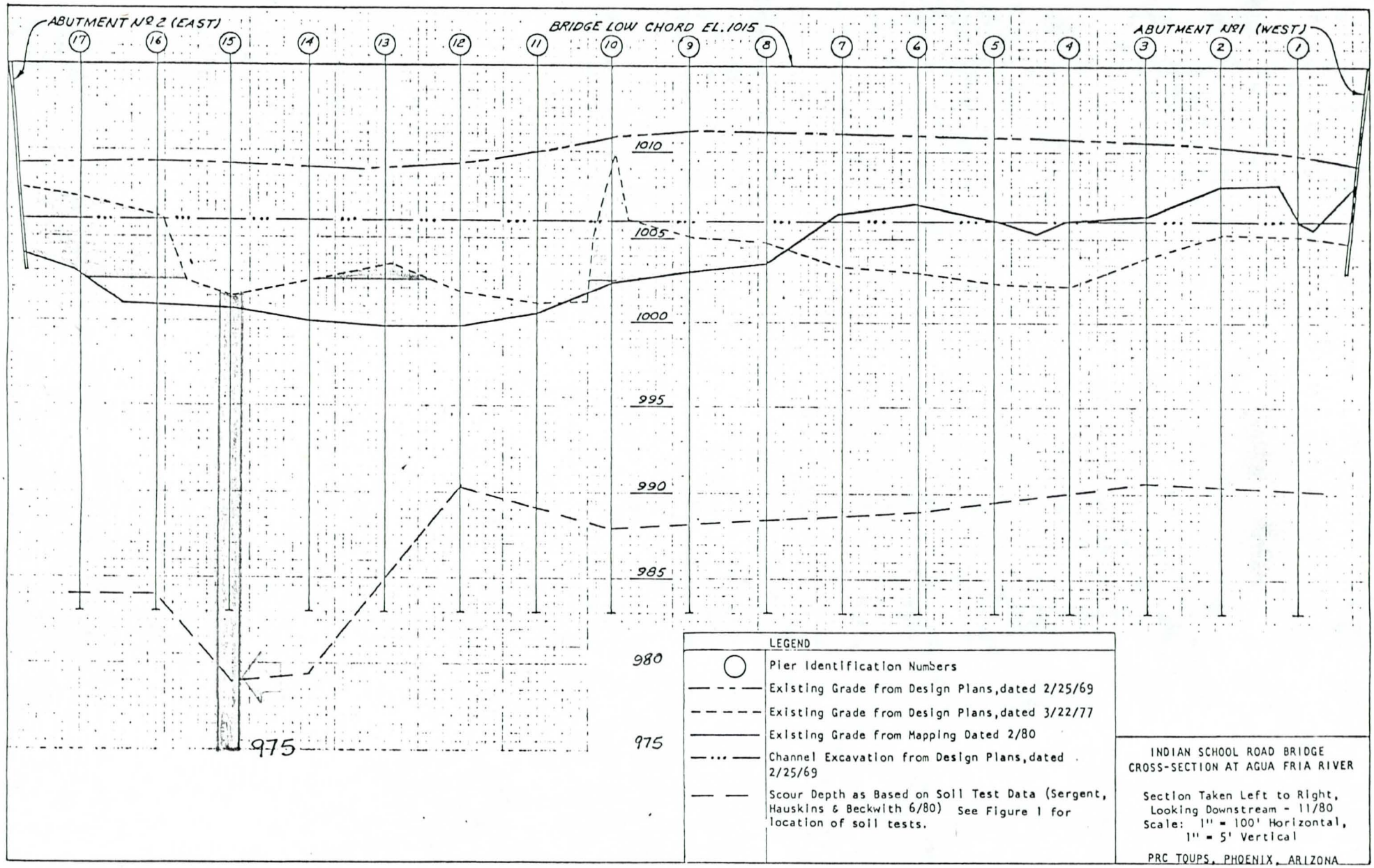


FIGURE 5

WITH DIKE INPLACE

CONFIDENTIAL



WITHOUT DIKE

FIGURE 6

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