Flash floods on bridge piers

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Flash Floods on Bridge Piers

Crues brutales sur des piles de pont

Einfluss von «Flash Floods» auf Brückenpfeiler

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SUMMARY

Floods of the so called «Flash Floods» type can yield momentarily runoff peaks entirely out of proportion with the rate of rainfall. These are caused by an abrupt increase of rainfall and runoff. A noteworthy example of this type of flood was the flash flood which occurred in Wadi Ad-Dillah and Wadi Itwad in the Kingdom of Saudi Arabia, on February 13, 1982. It caused severe damage to the newly constructed road from Taif to Jizan, and to several retention structures and bridges on that road.

RÉSUMÉ

Les crues du type «crue brutale» peuvent conduire à des débits de pointe bien supérieurs à ceux des crues normales. Elles sont causées par une augmentation brutale des précipitations et de l'écoulement. Un exemple remarquable de ce type de crue est la crue brutale qui a eu lieu dans les bassins versants des Wadis Ad-Dillah et Itwad dans le Royaume d'Arabie Saoudite le 13 février 1982. Elle causa des dégâts importants à la nouvelle route de Taif à Jizan, à plusieurs murs de soutènement et aux ponts de cette route.

ZUSAMMENFASSUNG

Hochwasser der sogenannten «Flash Floods» Typen können Spitzenhochwasser produzieren, die total ausser Verhältnis zu den Niederschlagsmengen stehen. Sie werden durch plötzliche Zunahme der Niederschläge und der Durchflussmengen verursacht. Ein bemerkenswertes Beispiel eines solchen extremen Hochwassers war dasjenige vom 13. Februar 1982 in Wadi Ad-Dillah und Wadi Itwad im Königreich Saudi Arabien. Dieses verursachte schwere Schäden an der neugebauten Strasse von Taif nach Jizan sowie an mehreren Stützmauern und Brücken.

1. INTRODUCTION

The magnitude of Flash Floods is controlled by several factors, the most important of which are the rate of increase and the intensity of the rainfall as well as the degree of saturation of the soil, especially if this is of the granular type and of high permeability. The flood which occurred in Wadi Ad-Dillah and Wadi Itwad in the Kingdom of Saudi Arabia, on February 13, 1982, caused severe damage to the newly constructed road from Taif to Jizan, and to several retention structures and bridges on that road.
Some of the bridges were destroyed fractions of a second before the incoming water wave hit them.

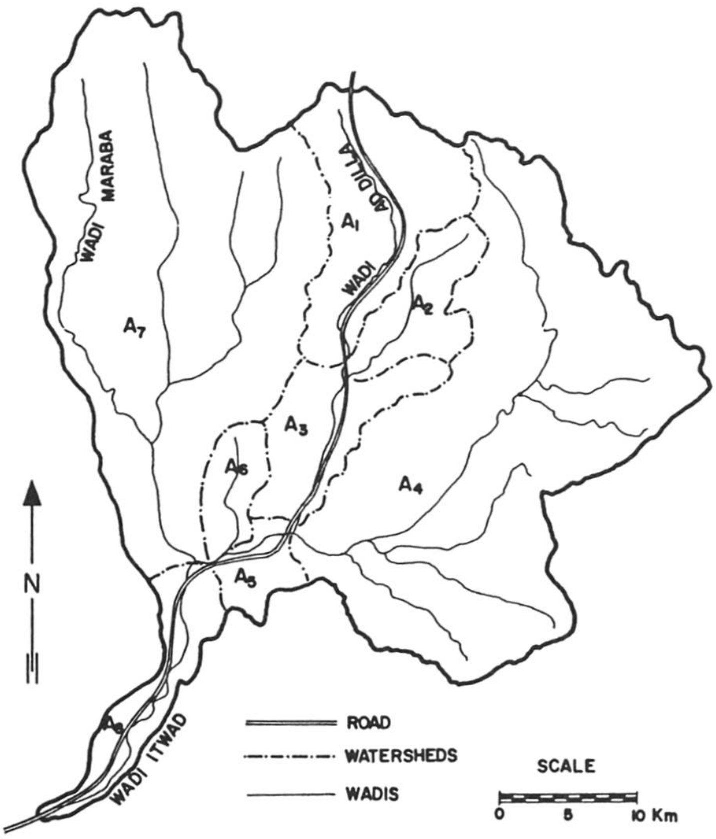

FIG. I CATCHMENT AREA.

This was caused by an instantaneous reduction of the shear resisting forces of the soil to practically zero, which led to loss of the soil bearing capacity and collapse of the piers. The catchment area of Wadi Itwad in Saudi Arabia comprises mainly of three subcatchments, i.e. the upper Wadi Itwad, the Wadi Ad-Dillah and the Wadi Maraba, totalling an area of 1425 km2 at the lower neck of their confluence (see Fig. 1). Road 54 connects the town of Taif through the Assir-Mountains to the town of Jizan in the western part of the country.

2. GEOMORPHIC SETTING

The steep topographic conditions of the escarpment change sharply from an altitude which varies from 2200 to 2700 m a.s.l. to the coastal plain over a distance of only some 40 km. The steep rocky slopes are sometimes interrupted at higher levels by isolated terraces which correspond to old flood plains and lakes now dissected by the deeply eroded drainage system.
In general the wadi consists of a flat floor between steep walls of rocky outcrops covered with stony debris. The wadi bed consists almost exclusively of alluvial deposits and only in very rare cases does bedrock outcrop. Pitting and geoelectrical investigations showed evidence that the wadi is a deeply eroded V-shaped valley in which the alluvial filling has a thickness of many tens of meters.

It is pertinent to mention here that the river bed is percolated by water more or less all the year round. This is evidenced by living fish that can be seen sporadically in small ponds in the lower part of the river.

3. THE FLASH FLOOD OF FEBRUARY 13, 1982

3.1 Damage Records

After a very heavy rainfall occurred in the whole catchment area of Wadi Ad-Dillah, Wadi Maraba and Wadi Itwad on February 13, 1982, a considerable part of the Road 54, from Ad-Darb to Wadi Ad-Dillah was destroyed by the floods. Concentrated damage and destruction was caused to bridges and retaining walls of the road located in the very narrow and twisty wadi sections. More than 12 newly built bridges were destroyed and several others damaged.
Eye witnesses to the events reported that the Wadi flow grew to a large wave, like a wall of water, filling the section of the wadi were it narrows, like a basin. An impounding effect raised the water surface and subsequently after the wave level had reached a certain height, a rapid drow down of the accumulated water mass occurred.
This extraordinary flood generated water levels and flow velocities that were far above those expected, from previously estimated and calculated. These are, however, comparable to data gathered from other flash floods which occurred in other regions of the world (see Coyne [2]; Lynch [1]; Hjalmarson [3], etc.).

FIG. 2 200 Ton Bridge slab after the flash flood.

Huge quantities of bed material were reported to have been dragged along the river bed. The peak velocities which occurred during the event could not be directly measured. From eye witness accounts these were estimated to be about 30 to 60 km/h, however these must be judged critically. Taking into consideration that huge bridge slabs of 200 tons of weight or more were moved hundreds of meters downstream, it can be safely assumed, that peak velocities of approximately 50 km/h occurred, (see Fig. 2).

3.2 Rainfall and Runoff

The original studies were based on an estimate of annual precipitations from an isohyetal map. According to this, 200 mm of precipitation a year was expected near the hydrological station of Ad-Darb. The values increase with increasing altitude.

They vary between 750 and 500 mm annually for elevations from 100 to 200 m a.s.l. and between 500 mm and 1000 mm annually for elevations from 1000 to 2000 m a.s.l. A later review of the values used for catchment areas larger than 50 km2 prompted the owner and the designer to use more conservative values of rainfall intensity, duration and runoff quantities.
Based on the Creager formula [4] the following runoff quantities were estimated:

Wadi Itwad	2500 m3/s
Wadi Maraba	1600 m3/s
Wadi Ad-Dillah (lower part)	1110 m3/s
Wadi Ad-Dillah (upper part)	745 m3/s

After the flood the wadi bed and the natural marks left by the high water levels were measured in order to calculate the discharge and reappraise the hydrological assumptions made. The resulting discharge values were more than twice the previously assumed values, and consequently were in disagreement with the rainfall data. The results show that additional factors have to be considered in order to explain the discrepancy between observed and estimated discharge values at stations belonging to the same catchment area.
The calculated water discharges from the marks which could be identified were as follows:

Wadi Itwad	5082 m3/s
Wadi Maraba	3368 m3/s
Wadi Ad-Dillah (lower part)	2115 m3/s
Wadi Ad-Dillah (upper part)	1750 m3/s

3.3 Failure Hypothesis

The comparison of the actual peak discharge value with those computed from the rainfall records indicated that the actual values were two or more times larger than the computed ones which seems to be impossible. However, it is remarkable that observations of this kind have already been made by scientists which have investigated relevant flash floods in other similar regions of the world, (see as representative examples Coyne [2]; Lynch [1]; Kinosita [5]; Heras [6]; Hjalmarson [3]; and others). The disagreement between peak flows calculated from rainfall data and actual peak discharges may be explained by fluidization of the river bed material.
Man made structures, specially bridge piers are vulnerable to flash floods. Some of them in Wadi Itwad, were damaged by the impact of boulders and rocks (which by the way, were greater and faster than previously assumed). Others were damaged by excessive erosion, and a few collapsed before erosion had time to act on them. As a matter of fact, eye witnesses assure that they saw a pier moving from its place, fractions of a second "before it was hit by the main incoming water wave". It has already been mentioned above that eye witnesses are to be judged critically, however, this point makes sense as will be seen later. It is this small detail that is able to bring new light into this subject.

Wave-induced pore pressures and soil liquefaction in front of a water wave produced in saturated soils have been reported in recent years by several authors (e.g. Sleath [7]; Madsen [8]; Nataradja and Singh [9]; Zeevaert [10], etc.) Similarly in this case, it is postulated that the incoming water wave in the wadi bed generated a pressure wave in the saturated soil. This pressure wave has the ability or property to travel through the saturated granular soil at a velocity which is greater than the velocity of the water wave on the surface of the river bed (see Richart et al.,[11]). Therefore, the pressure wave will have to travel in a pulsating or intermitent form in front of the water wave (see Fig. 3).

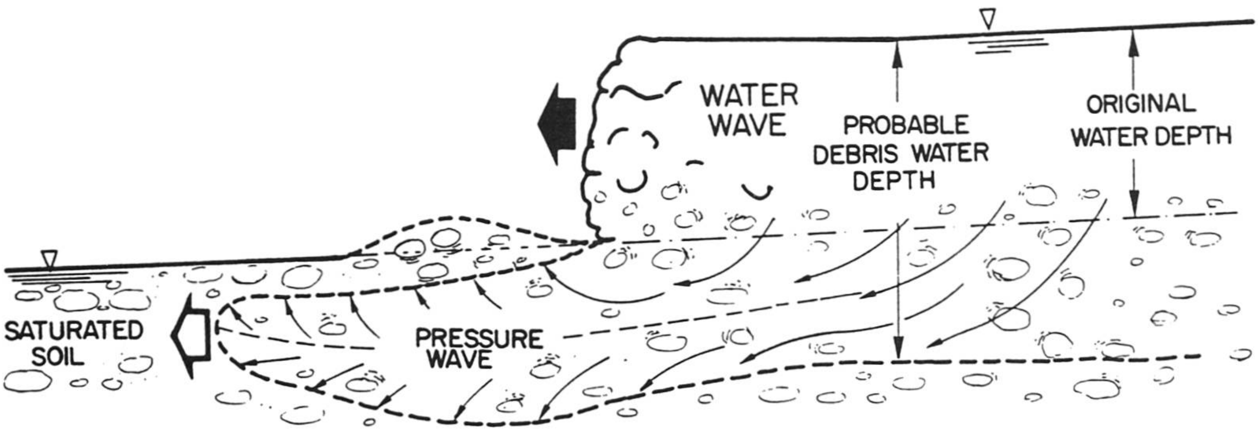

FIG. 3 SCHEMATIC VIEW OF A FLASH FLOOD WAVE.

The pressure wave will increase the magnitude of its pressure when the water wave increases in size. If the size of the water wave continues to grow, there is a moment in which the pressure wave will reach a value equal to or greater than the effective confining pressure and the shear strength of the soil will become zero, i.e. it fluidizes. Fluidization, as opposed to liquefaction, is a mechanism by which a cohesionless material achieves a viscous liquid-like condition by forcing a fluid from an external source upward through the sediment, until the immersed weight of the grains is balances by the total fluid drag, (Othmer [12]; Leva [13]; Kunii and Levenspiel [14]).

It is postulated that this temporary fluidization of the soil in front of the water wave caused those piers to collapse or to sink before erosion had time to act. This temporary fluidization of the soil is also the reason which allows the incoming water wave to enrich and to reinforce itself with not only the water retention pirated from the saturated soil, but also with the fluidized soil debris as well. This explain why the measured discharge runoff can be, in certain cases, far greater than the calculated discharges from the rainfall records alone.
Figure 4 gives a schematical interpretation of the sequence of events suffered by at least one of the bridges of the catastrophic flash flood that occurred on February 13, 1982. The photographs of figures Nr. 5, 6 and 7 taken after the catastrophe, demonstrate that the piers have sunk and moved several decimeters and meters but where not broken, and the displacements are evident.

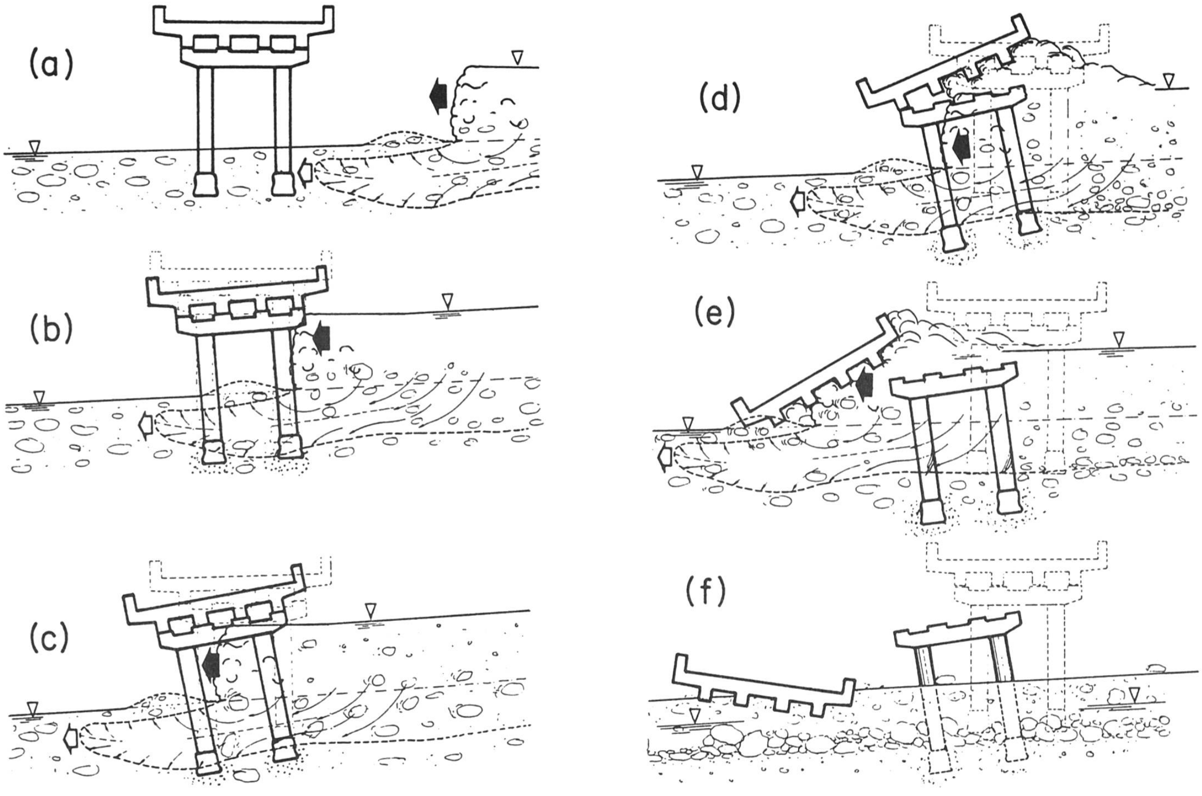

FIG. 4 SCHEMATICAL VIEW OF PROPOSED FAILURE MECHANISM

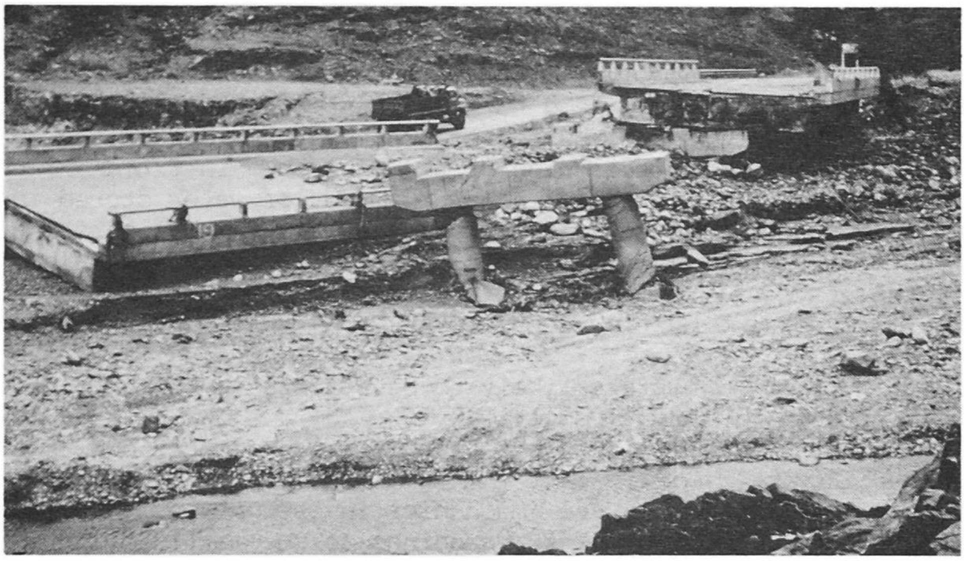

FIG. 5 Bridge destroyed by the flash flood of February 13, 1982.

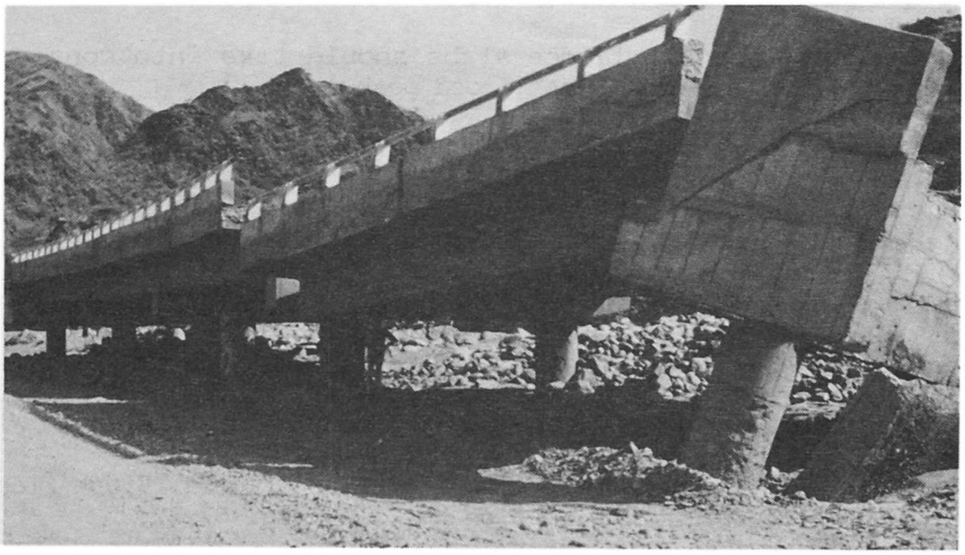

FIG. 6 Piers sunken due to fluidization of the river bed.

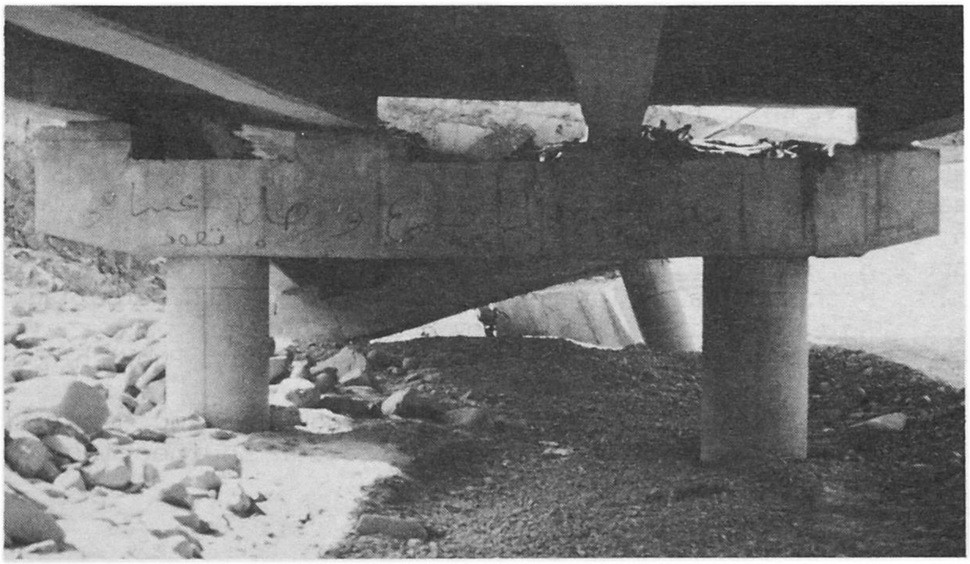

FIG. 7 Support structure damaged by the flash flood.

4. CONCLUSIONS

In the case of a flash flood, the depth of water level will increase not only due to narrowing of a cross section and to back water effects of transient flow conditions, but also because of the increment of water and debris quantities. This phenomenon is caused by the loosening of the river bed in front of the incoming water wave by the mobilization of a large amount of water stored in the soil of the river bed. The subsequent fluidization enables the mobilization of soil debris as well. This changes not only the instantaneous peak discharge in the water wave, but also its density, due to the influence of the very large amount of debris and boulders carried by the river.

Bridge piers in rivers which are likely to be affected by flash floods should be designed in the most conservative way.
The most important steps to be taken to avoid bridge damages due to flash floods are:

1. To check with a thoroughly soil mechanics investigations, the possibilities that the soil may have on its surroundings to become fluidized in any time of the usefull life of the bridge.
2. The foundations of the bridge piers should be deep enough.
3. To provide pier protections, inclusive for the part below the surface of the river bed.
4. The design height for the bridge slabs should take into consideration the possibility of an incoming flash flood peak.

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