CALAMITY FLOOD AND BLOCK PAVEMENTS BEHAVIOUR

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The paper describes an investigation conducted in the area of North-Eastern Italy where, in November 1994, a dramatic flood reached the maximum peak within 30 minutes, destroying walls of houses and damaging asphalt pavements but leaving quite safe the concrete block pavements, except where ditches occurred.

A tentative technical explanation will complete the accurate survey conducted after the disaster.

INTRODUCTION

During the first days of November 1994, north-western Italy was struck by a violent calamity flood which mainly hit the region of Piedmont.

The flooding of rivers, the landslides and the slipping of the banks have all caused serious damage and unfortunately claimed many casualties.

In just a few hours entire populated areas along rivers and streams have been swept away, while numerous bridges and roads either collapsed or were unfit for use.

The town was completely paralysed for many days. Damage was so extended that reconstructive work and reclamation of land are still being carried out today.

Unpredictable or exceptional events of this kind can sometimes question or even disprove studies and research that had been carried out to analyse performance and to evaluate working behaviour and reliability of certain products or systems.

In fact, the November 1994 flood has, technically speaking, upset many construction theories and has lead us to question some cognitive aspects of construction which had up to now been customary.

On the other hand, there are times when such unpredictable events act as testing elements. This was the case of Renzo Piano's construction in Japan which resisted last year's terrible earthquake.

Similarly, the flood allowed us to test block-paved surfaces in a real life situation.

Through research studies, we have up to now analysed block paving behaviour when subjected to various working loads. We have also evaluated and verified on special test fields force distribution between units; the role and importance of

the joints and of their saturation as well as the best shape and thickness to have according to the use of block paved surfaces and the types of sub-grade.

Owing to its violence and destructive force, the flood has allowed us to carry out exceptional studies.

STUDY

This study was carried out in the town of Santena (Turin) which was particularly struck by the flooding of the stream Banna.

The stream Banna runs south of the town and, flowing from south to north/ north-east it flooded the whole north eastern area where most houses are located.

The town comprises some old two/three storey buildings located in the historical centre of town, some new apartment buildings located in the higher areas (not involved in the disaster), and a newer area of detached houses.

Eighty-five percent of the town was hit by a powerful hydraulic force with amazing speed which, in a few minutes, swept away all types of manufacts.

Just like most of the containment barriers that had been raised, some indoor paving (such as the one in the maternity school), walls as well as partitions of garages and cellars were swept away. In some buildings the compression of air caused by the sudden entrance of water stripped the slabs of garages.

In evaluating this study we must keep in mind the exceptionality of this event and the speed with which it took place - in fact most damage occurred during the first phase of the flood.

The type of pavement covering the area is extremely homogeneous, consisting mainly of asphalt on the main streets, natural stone along the side roads (these were not involved by the calamity) and extensive block-paved surfaces both on public and private areas.

The study was carried out in the area mostly hit by the flood, which consisted mostly of public works (the main square, the sidewalks) and many of the newer detached houses. This area was mostly covered by block-paving.

TYPES OF BLOCKS AND YIELDING CHARACTERISTICS.

A surface of approx. 7,500 square meters paved with 6 cm thick blocks of different shapes was studied.

The distribution of block paved areas in various town activities and their use, the types of deformation and

failure which occurred as well as the causes and effects of these failures are all highlighted in Table 1.

The pattern of failure is typical of yield due to the deformation of the sub-grade caused by the flood. Failure was in places more concentrated and in others more spread out according to the different types of impairment.

Before proceeding to the analysis of the outcome of the study, note the graph showing the course of the flood in relation to lapse of time and intensity (Fig 1). As you can see, the initial impact lasted approximately an hour. This first phase was followed by a decrease in intensity, then by a stabilisation period with continuous loads due to water, and finally, by an extremely long downflow period.

Three distinct phenomena were observed:
- Loosening of single blocks from their seat
- Adaptation of block surface to bottom ground profile
- Suspension effect

The first case (Fig 2) was observed when the water flow met with an obstacle which contrasted it.

The persistence of highly accelerated water induced torsional and vertical forces which completely removed the sand in the joints between blocks and swept away the laying course (sand) thus removing the interlocking ties and loosening the blocks within their seats without however removing them.
It is interesting to note how only the laying course was affected by the action of the water, while the sub-grade remained practically unaltered.

In Fig. 3 we have tried to visualise the phenomenon described above. It shows how the sub-grade was not significantly deformed, but was relatively stable throughout the course of the flood.

As the graph demonstrates, it takes a relatively short period of time for the phenomenon to reach the critical point where the single blocks are loosened. On the other hand, the laying course deforms and migrates until it is completely removed.

In the first part of the evolution of the calamity, a high concentration of tensions occurred causing, in a relatively short period of time, the emptying of the sand joints right after that of the laying course. The blocks started moving only after and owing to the emptying of the joints. The fact that, even though loose, the blocks remained in their places implies that the hydraulic force did not penetrate beneath the flooring to boost a macroscopic migration.

The second case that was observed represents, even though limited if considering the extent of block-paved surfaces, most of the failure observed. Failure in this case was due to the sagging of the sub-grade (Fig 4).This sagging occurred mainly because the lateral contrasts to the flooring were dislocated. This resulted in a lack of support around the perimeter.

Around these areas, sub-grade materials were swept away causing the blocks to adapt to the new shape of the deformed base, without however escaping from their position.

In the figure that follows, (Fig 5), the course of the various deformations is shown. In this case there was an almost immediate deformation of the sub-grade, followed by a migration of the laying course. At the same time, the blocks adjusted to this deformation of the sub-grade without however being undermined.

Note that in the cases mentioned above, the loosening of the blocks did not result in the breaking of the corners nor did it result in the breaking of the blocks. There was an excellent cooperation in the distribution of forces between the blocks. In some cases, an interlocking action created a suspensive effect on the surface where the sub-grade had been dragged away. This is the third case observed in this study (Fig 6).

In consequence of a strong erosion of the weakest layers of the sub-grade, we observed areas where medium sized ditches occurred so that the blocks were left without a base to rest on.

The deformation graph (Fig 7) shows how the deformation of the sub-grade, and therefore the laying course, was indeed very rapid, but limited to a small area thereby forcing the blocks to be in direct contrasting contact. Even though this brought about an initial deformation of the top layer, it facilitated a transmission of forces due to a reciprocal supporting action. The deformation of the blocks did not therefore result in a complete collapse but in a stabilisation of the area.

The suspensive effect of the surface enhances the interlocking mechanisms through the joints, which were obviously not completely emptied by the rapid hydraulic action which was stronger in the sub-grade than in the surface.

Just like in the second case of adaptation to sub-grade deformations due to the removal of lateral contrasts, the non-rigidity of the pavement reduced the likelyhood of deformations.

Since the land in the area has good carrying capacity, the types of sub-grades are on the whole quite similar,

consisting of a crushed and settled mix which was then rolled and pressed to 15/20 cm.

The use of geotextiles such as the filter for the draining of surface water and for laying course soil retention were found to be "passive" in their action, probably due to the exceptionality of the event.

Doubtlessly the deformation of the sub-grade is related to the materials used as well as to the working loads to which the pavement was subjected to.

In this specific case, where the loads were represented by a not too easily quantifiable addition of forces whose result was a variable dynamic effect, the deformations observed were mostly caused by the lack of lateral support rather than by a specific action.

CONCLUSIONS

The top layer acted as protective layer of the sub-grade, the weakest element of the pavement, offering a global compact and smooth surface thereby allowing for a better flow of water on the surface. It also limited water infiltration, maintaining an even and compact global surface.

This feature proved to be efficient in this specific case where the action of the water was tremendous both in terms of quantity and in terms of speed.

Generally, and under normal conditions, block pavements contribute to the flowing of surface water guaranteeing a permeability which allows drainage and limits water penetration.

The elasticity of block assembly has reduced the undermining of the blocks which turned out to be re-usable once the flood retreated.

Damages of block-paving were on the whole quite moderate, maintenance will therefore not require skilled labour or high costs since it will involve re-using the same material and simply adjusting the sub-grade.

Tab.1: SURFACE OF RESEARCH (7.500 Mq.)

1.1: Activities and use (%)

Blocks mm.	activities			use		
	industr.	private	public soil	pedestr.	light vehicles	heavy vehicles
60	10	50	40	5	85	10

1.2: Types of deformations and failures (%)

extensive	undermining of blocks	deformations	no deformations
5	2	8	85

1.3: Causes of failures (%)

raising or sagging sub grade	loss of lateral contrast	chasm
1.5	98	0.5

1.4: Removals (%)

laying course	total sub grade
15	85

Fig.1: COURSE AND EVOLUTION OF THE CALAMITY

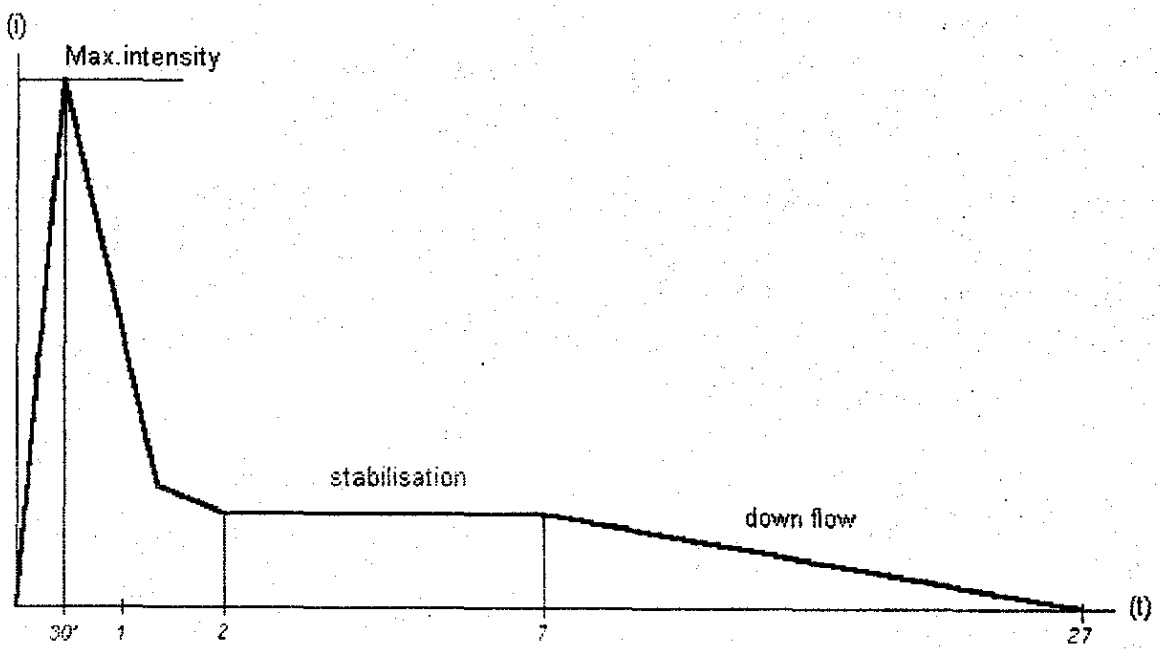


Fig.2: OPPOSITION TO FLOW BY AN OBSTACLE
During phase of maximum intensity

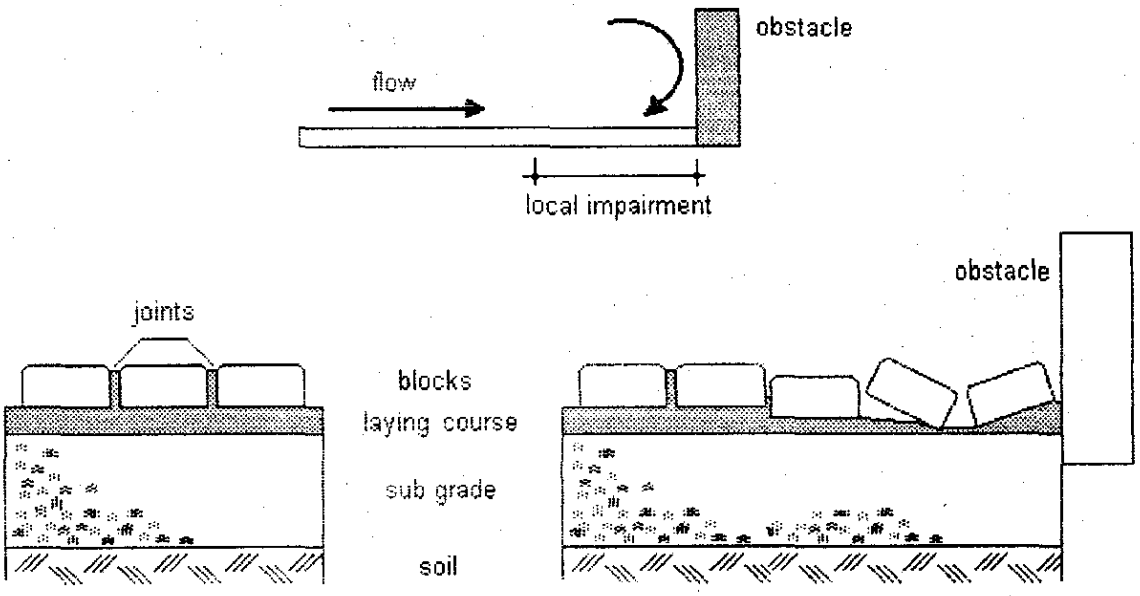


Fig.3: FIXED OBSTACLE FAILURES

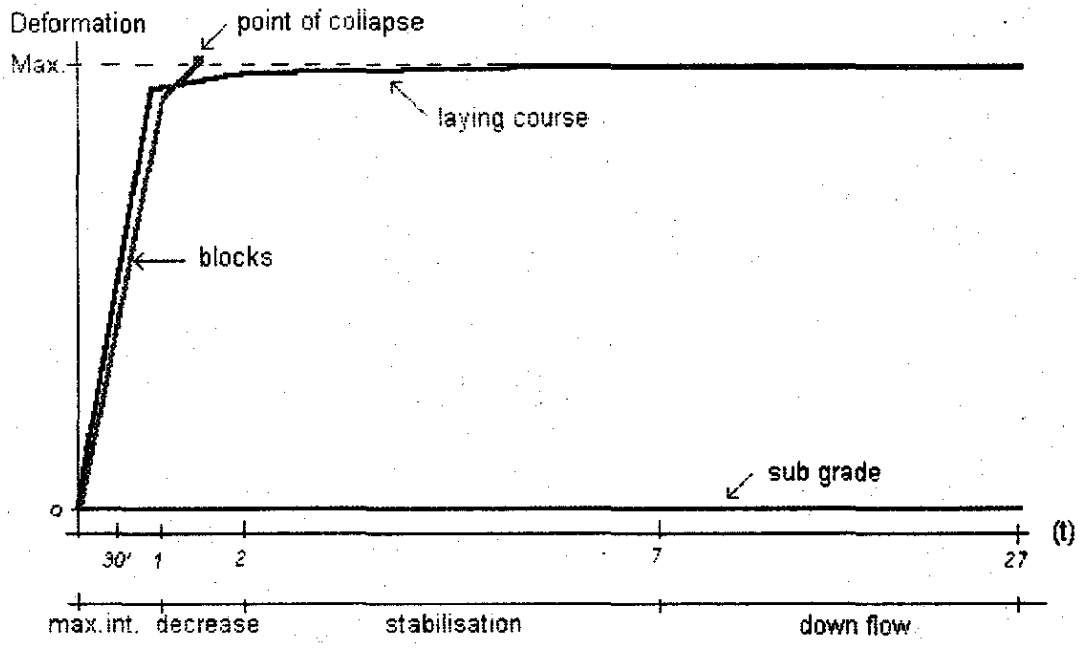


Fig.4: OBSTACLE KNOCK DOWN
failure of lateral contrast

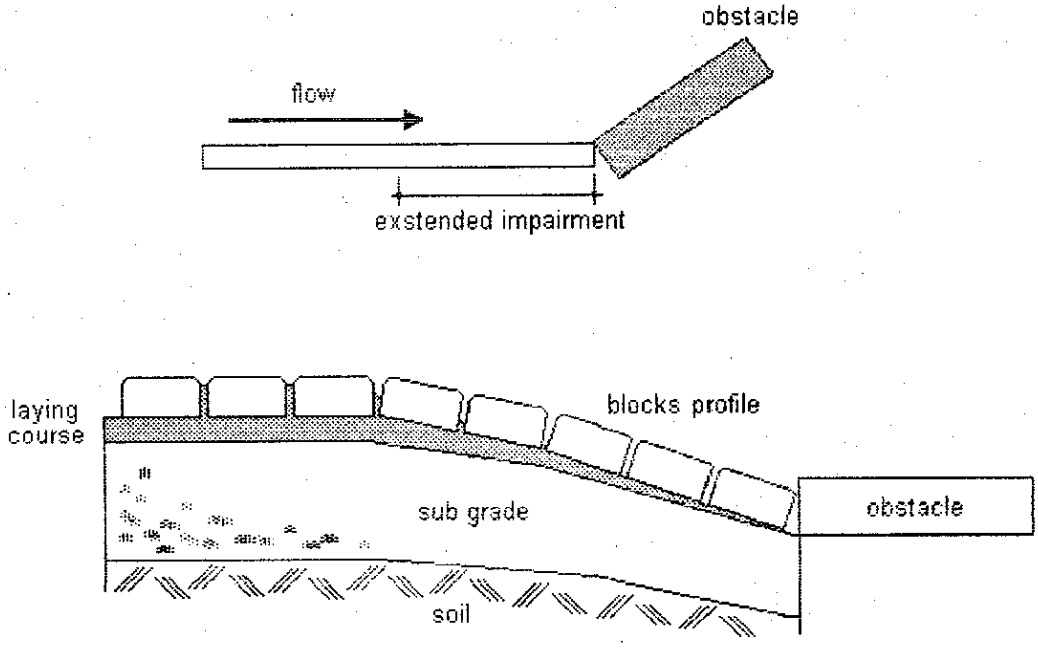


Fig.5: FAILURE AND KNOCK DOWN OF LATERAL SUPPORT

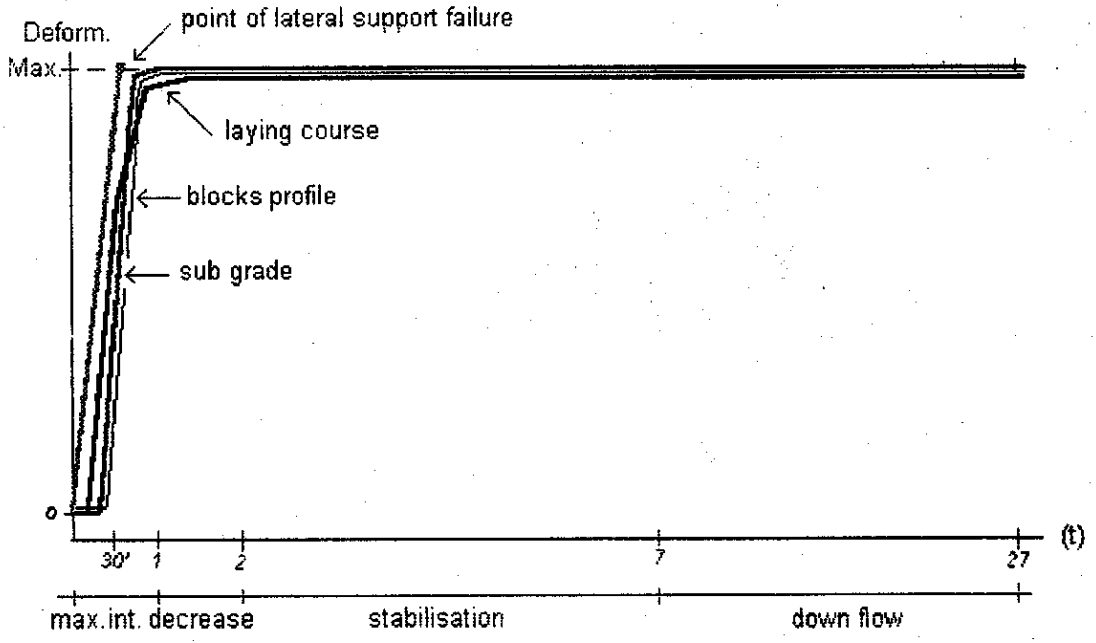


Fig.6: SUSPENSIVE EFFECT
local effect of sub grade erosion

Distribution of strain among blocks

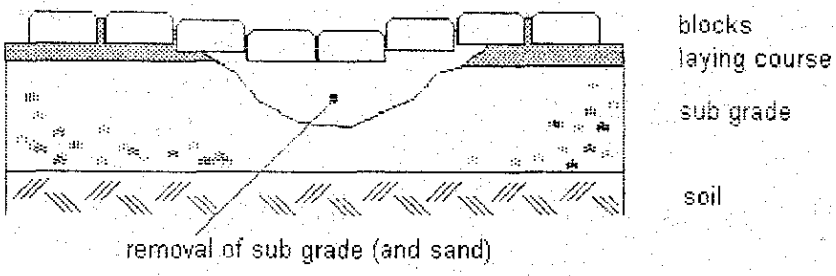


Fig.7: FAILURE DUE TO SUSPENSION EFFECT

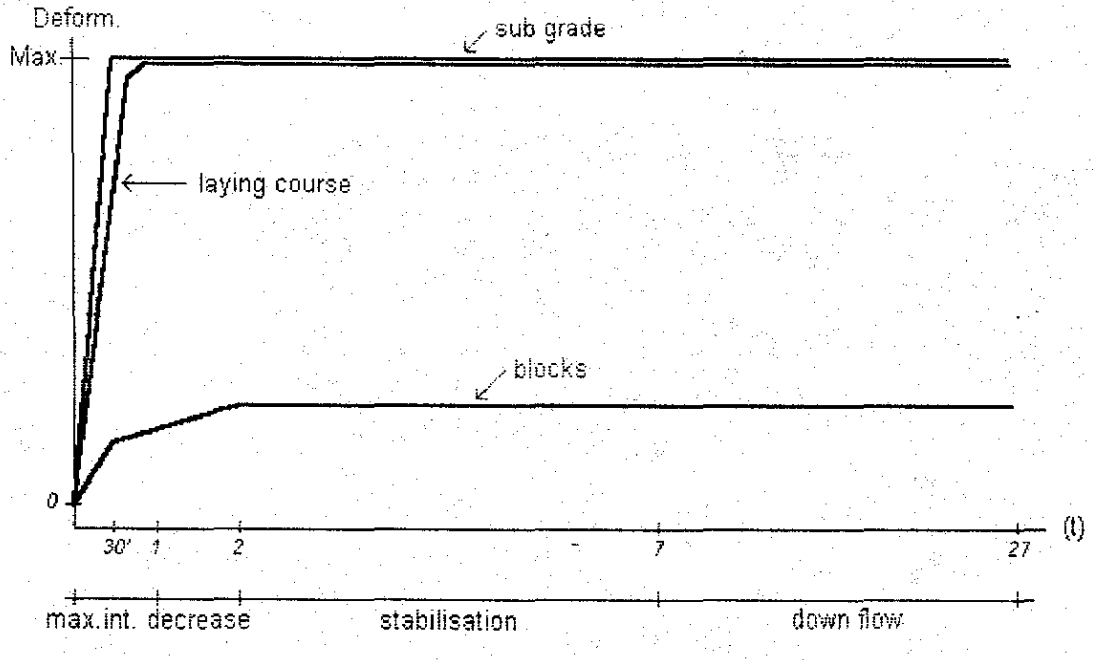




Photo 1: view of calamity



Photo 2: fixed obstacle - local impairment



Photo 3: failure of lateral contrast



Photo 4: new blocks profile



Photo 5: suspensive effect



Photo 6: perfect condition after 4 m.of water