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Report on Mission to Luang Prabang

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1 My brief

I was requested to undertake a mission on behalf of ICOMOS and UNESCO to Luang Prabang in the Lao PDR, to examine riverbank erosion and minor landslipping, and to report on, *inter alia*, proposals for stabilisation of the affected area. The town of Luang Prabang is situated within a conservation area, designated a World Heritage site largely in respect of its unique architecture.

A remedial scheme has been designed, and there have been concerns expressed about this design, both in respect of its technical detail, and also in terms of aesthetics: for example, will its appearance detract from the efforts made to conserve the appearance of Luang Prabang and the Phousi hill from vantage points also within the conservation area?

I was supplied with a variety of documents, including a site investigation report, information (including extensive construction drawings) for the remedial scheme, and documentation regarding the World Heritage status of the site. I have read and considered this material.

My visit to the site took place in the period 14-16th March 2001. During my visit, I was greatly assisted by the staff of the Maison du Patrimoine, especially their Architect Laurent Rampon, and I wish to record my gratitude for this assistance.

2 Geography

The historic part of the town of Luang Prabang is built on an elongated hill at the confluence of the Mekong and Nam Khan rivers. The Nam Khan is a tributary of the Mekong. The hill rises considerably above the flood levels of either river, and the highest point is referred to as the Phousi hill.

The Nam Khan river flows directly towards the Phousi hill, before being deflected sharply to the right where it comes into contact with the bedrock of the hill. It flows along this alignment for a short distance, before turning sharp left, whereupon it meets the Mekong river. I conclude from the general geological structure and this unusual arrangement of rivers, that it is possible that the rocks in the Luang Prabang area have been upthrust in comparatively recent geological time, causing changes in the courses of the two rivers.

It is conventional wisdom that the erosive power of a river is concentrated at the outside curve of its bends. Whatever the cause of the pattern of rivers, the abrupt change in direction of the Nam Khan river means that there is one of these outside curves with the potential to affect the road and slopes in the area of Luang Prabang with which my mission is concerned.

3 Geology

My colleague at Kingston University, Dr R. B. Stokes, has mapped the Luang Prabang area in connection with oil prospecting. He provided me with a description, which I reproduce in a short Appendix.

During my visit I examined the exposed rocks in the Phousi hill, adjacent to the failed section of wall. They are sedimentary rocks, with interbedded limestones, sandstones and shales. The rocks are highly fractured, and dip at about 30° to the horizontal in a northerly direction. This combination renders it unlikely that sliding of significant parts of bedrock of the Phousi hill towards the Nam Khan river will occur.

My photograph, Figure 1, shows the rocks that I examined. The dip can be clearly seen. I have highlighted one of the beds of shale.

Figure 1. Rocks adjacent to the road dipping into the Phousi hill.

The road and slopes down to the Nam Khan river are not cut into the bedrock. Instead, they are both formed in a wedge of soil. I have sketched this in my Figure 2, which is not to scale. Bedrock outcrops in the floor of the Nam Khan river, and in places at the foot of the slope. It is better visible when the Nam Khan river level is lower than at the time of my visit, but even at this time, turbulence in the river marks the position of prominent outcrops.

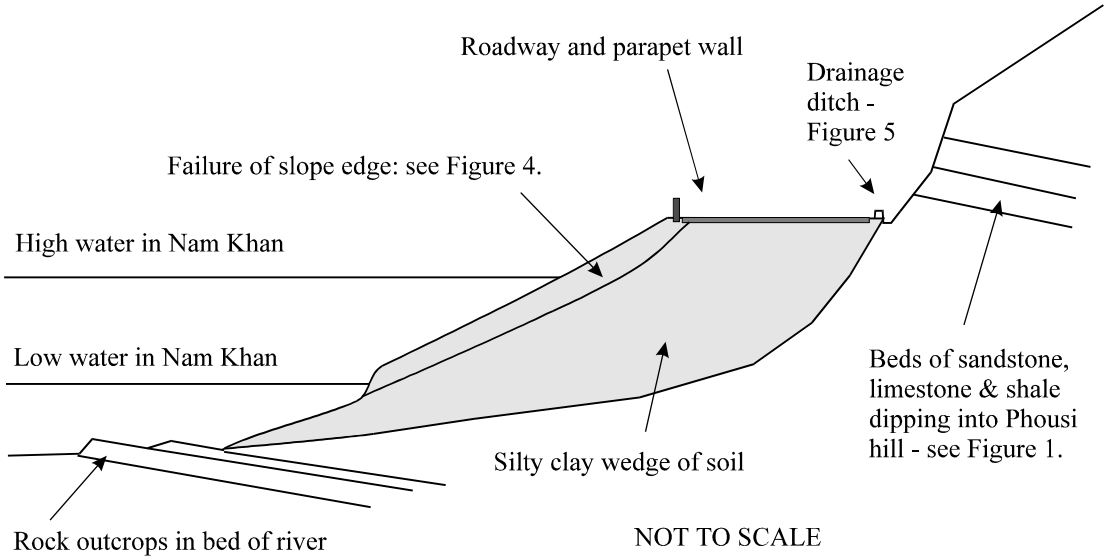

Figure 2. Sketch section of affected slope showing features mentioned in the text.

The soil failure that prompted the design of river erosion control and slope stabilisation works is a small-scale slip of the slope formed in this wedge of soil. It is significant only in that it threatens a major access to the town: it does not threaten and significant parts of the historic town centre or its buildings, except perhaps on a geological time scale measured in thousands of years.

4 Origin of the soil wedge

It is quite clear that the soils present at the site of the failure have some interesting characteristics. They owe their origins to the peculiar behaviour of the Nam Khan and Mekong rivers. Both of these rivers carry a large load of sediment. At times of low flow, the Nam Khan has a high velocity, and is erosive. Paradoxically, at times when the river level in the Nam Khan is high, the Mekong dominates the flow pattern, and velocities in the Nam Khan are reduced. I understand that there is sometimes a reversal of flow. Under these conditions, deposition of sediment takes place. Soils deposited are primarily silt, with some clay and sand. Some of this sedimentation even takes place on the outside of the river bend.

In the particular site under consideration, there are also fills, used to make up the road level; mud, washed down the Phousi hill; and a small amount of discarded refuse.

It is to be expected that under natural conditions, the wedge of soil would change in size from year to year. Some years, the deposition would be greater than erosion, and *vice versa*. Erosion, as far as I can see from my visit, takes place primarily at low

river levels, and is concentrated at the toe of the slope. This can lead to the slope as a whole being undermined, and the occurrence of slips of the type that recently affected the road. During my visit I was taken to the opposite side of the river to get a better view of the slope. Figure 3 shows the slopes a little upstream of the failure site. The photograph was taken from a vantage point on the opposite side of the river. The erosion at the toe of the slope can be seen both to the right of the house on stilts, and also in the small island formed of sediment to the left of the house. This island appears to have formed comparatively recently.

Figure 3. Upstream of the failure site. Erosion is taking place to the left of the boat and orange figure in the sediment island, and also as the river turns, to the right of the house on stilts. The high sediment load in the Nam Khan river is evident from its colour.

In my view, slip failures in the soil wedge are inevitable. A view of the failed section of the slope is presented as my Figure 4. Some intervention in the dynamics of the situation is necessary to ensure that the failures occur infrequently.

5 The failure affecting the road

Quite clearly the failed area suffers several defects in construction. There are no arrangements for scour (erosion) protection in the slope below the road. This slope, as I have explained, is formed primarily in very recent alluvium, and it is subject to

changes in shape as a result of the interaction of flow patterns in the Nam Khan and Mekong rivers, as well as the effects of weather and human activity. Furthermore, the retaining wall for the road and parapet wall has no foundations of any significance. This structure is primarily cosmetic, and has little or no capacity for supporting the road.

Figure 4 (left) shows the site of the main failure, and how it affects the road. Figure 5 (right) shows the drainage ditch adjacent to the rock face (also shown in Figure 1). The wet area along the verge of the road shows where rainwater has lain, unable to escape via the ditch.

Water running off the Phousi hill is caught in a drainage ditch (Figure 5). These ditches are very widespread in Luang Prabang, and carry not only rainwater, but also waste water. I know of other cases elsewhere in the world where such drainage ditches leak, and feed water into the soils under roads (see sketch Figure 6). The ingress of water from this source can sometimes be serious for soil stability. I have no evidence that this drain at Luang Prabang is a problem, but in the reconstruction, care must be taken to ensure that the drain is not leaky.

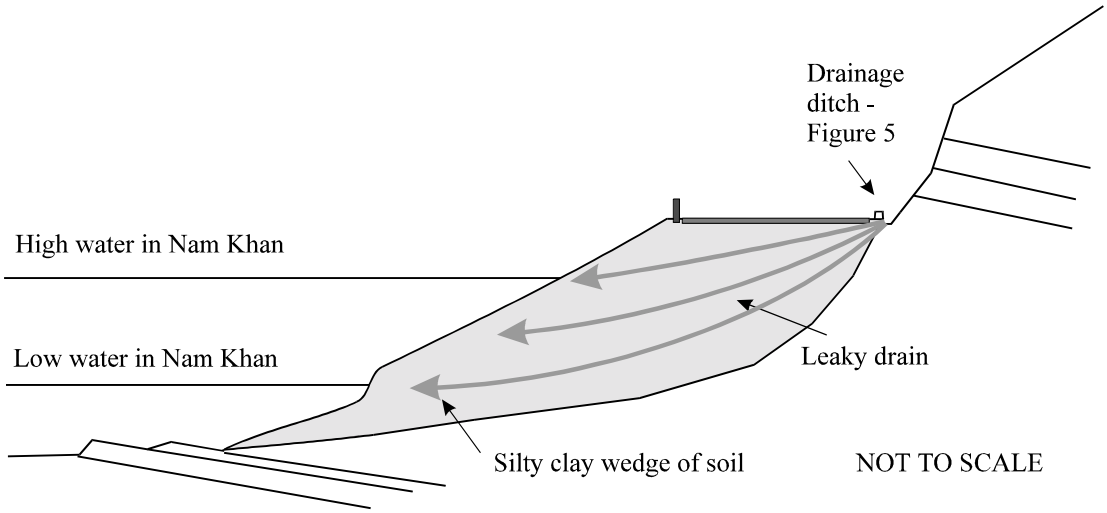

Figure 6. Water flows from leaky drains – a speculative illustration of possibilities .

Rainwater falling on the road cannot easily enter the ditch, and must find another route to enter the river. I do not believe that the highway drainage system is adequate for maximum rainfall events. Rainwater has clearly poured off the road in the area of the slip failure.

6 The gabion wall

Faced with the problems of this site, I would recommend a gabion form of construction. It provides erosion protection to the slope at all river levels. Because it is very permeable, it lets out water from the ground. It is to be built (according to the plans) with reinforcement extending back into the slope. The resulting mass of reinforced earth is capable of supporting the slope.

I have not repeated the stability calculations, but experience of this form of construction and the design techniques used by gabion manufacturers gives me confidence that stability of the soil slope will be greatly improved. I considered that the soil investigation was minimal, and the stability analyses carried out were excessively simplified, but nevertheless, a satisfactory result was obtained.

I believe that there are some issues associated with the downslope extent of the gabion wall which need to be addressed.

7 Appearance of the gabion wall

The gabions are to be made of plastic coated wire baskets, infilled with hand-packed stone. Local limestones will be used. Hand packing creates dense gabions that do not settle within the basket. They are like traditional dry-stone walls. It will not be adequate to pack the gabion baskets by means of an excavator. If that is done, they will not be so densely packed, and will settle and go out of shape. Hand packing has the disadvantage that it is slow, but the results are worth it.

Undoubtedly, the rock gabions will look out of character with the protection area initially. Their appearance is geometrically regular, and they will initially be bare of vegetation. However, several factors will change this over a few years.

- The rocks will weather, and take on the appearance of the natural rock faces in the vicinity. Many concrete or rendered brick faces in Luang Prabang are covered by irregular black deposits which I take to be a type of lichen growing under tropical conditions. Such colouration due to organic growth will undoubtedly occur.
- In the next rainy season, the Nam Khan river will deposit sediments in between the rocks in the gabions. The mud will stain the rocks in the gabion baskets to the normal colour of soils in the area.
- Vegetation will become established very quickly.

In my view, it is not worth planting trees or shrubs on the gabions, as such vegetation is out of character on the lower slopes, and may not survive being flooded annually. Grasses will flourish.

In future, the terraces formed by the gabions will allow access to the slopes, including access for spectators to any boating events held on the Nam Khan river. This could be an environmental asset gain from the scheme, and help segregate spectators from road traffic..

8 Downslope extent of the gabion system

In my opinion, the gabions must be founded on rock. Rock is at an irregular level at the foot of the affected slope. Sometimes it is under river level. The levels could be made up with mass concrete. This would only rarely appear out of the river, and would be indistinguishable from the natural rock when it was made dirty with river mud. Gabions could be built on this concrete before it was properly cured, (i.e. only days after placement) because the pace of construction is slow, and the concrete would be fully cured by the time it was fully loaded. Masonry could also be used.

Since the grade of concrete is not significant, it could even be placed underwater. It could incorporate boulders (often termed “plums” in UK engineering practice).

During my visit I held a conversation with an engineer from the construction company which is going to build the gabion scheme. He convinced me that it was his intention to extend the gabions or other protection down to bedrock. His company had already undertaken some of their own boreholes to test for the depth of bedrock. On the upstream side of the scheme, bedrock outcrop at the foot of the slope was below river level. He told me that he was contemplating construction of a cofferdam to keep Nam Khan river water out of the excavations he would need to make in order to found the gabions on bedrock. I consider that this is a very appropriate thing to do, but it is complicated and difficult. Notwithstanding that there was the possibility of a language-based misunderstanding of what he was telling me, I was reassured that the construction is in safe hands.

If the gabions are not founded on rock, the scheme will be fundamentally flawed because erosion at a low level in the soil wedge would undermine the gabions. This could even take place at low river levels.

9 Temporary works

The planned scheme has a large amount of excavation. This is necessary to provide space for the reinforcement (reinforced earth backfill) for the gabion wall. I consider that it is possible to do this without destabilising the hillside, because above road level the hillside is mainly bedrock, and the dips are away from the Nam Khan river.

These excavations will almost certainly require road closure. That much is evident from the extent of the excavations shown on the design drawings.

In the river, a temporary works cofferdam is required. There are no stability issues relating to the hillslopes in the use of a cofferdam, but it must be removed on completion of the project, otherwise it could lead to erosion downstream as a result of alteration of the flow patterns in the Nam Khan river.

10 Lateral extent of the gabion system

I considered that the gabion system was sufficiently extensive to deal with the most obvious area of instability. Upstream of the gabions there is an area of potential risk of erosion. The scheme does not preclude a future extension upstream. Downstream, the scheme as designed has an area of gabions only in the upper slope. Provided that the area of scour erosion does not migrate downstream, these limited gabions do provide some support for the parapet wall and footway of the reconstructed road.

However, in my experience (this experience is mainly associated with coastal works, not river control) the area of erosion attack *does* migrate downstream after remedial works have been constructed. The small scale gabion construction would then need to be removed when this section of slope was reconstructed, and would be somewhat wasteful. On the other hand, a full slope height gabion construction is relatively expensive, and also the foot of the slope is better protected as bedrock outcrops at a progressively higher elevation downstream of the failure. On balance, therefore, I am unable to insist that a complete scheme is constructed in this area – there is no obvious downstream limit to which remedial works should be constructed.

11 Highway design issues

In my opinion the design of the road with a footway on the side nearest to the river is an excellent compromise. It keeps pedestrians away from the traffic by means of a high kerb. It also prevents heavy wheel loads from coming close to the edge of the construction, and thus improves the stability of the retaining wall. It also helps reduce vehicular impacts on the small balustrade, which does not look as if it is designed to resist vehicle impact.

I understand that it is proposed to widen the highway in the area of the river protection works. The affected section of road is part of a road system that encircles the historic centre of the town of Luang Prabang, and gives convenient access without requiring that vehicles travel through the historic and commerial centre of the town. This is a very sensible traffic planning system. However, I think that enlargement of the width of this road as part of the river erosion control works is undesirable for technical reasons. Although I am not a highway designer, this road does not connect to wider roads at either end of its length, and a wider road in this location would serve no useful purpose, other than to increase vehicle speeds. The consequence of this, at both ends where the road changes direction and narrows, would be an increase in vehicle accidents.

If the road was widened by removal of the footway, it would de-segregate pedestrians and vehicles. Furthermore, it would increase the opportunities for heavy vehicles to overstress the verge, or to impact the parapet. Neither of these is desirable.

If, alternatively, the road was widened by increasing the steepness of the gabion construction, then this has a small deleterious effect on overall riverbank stability.

I only briefly visited the Mekong riverbank side of the town. At low levels of the river, there is an attractive sandy strand or beach here. A part of the road system which runs around the town runs along this strand, above normal high river level in the Mekong. I understand that there is a proposal to widen this road and to build training walls to control river flows and erosion. I saw no evidence of erosion, and

would recommend extreme caution in doing anything that could affect the hydraulics of the Mekong in this area. In particular, river training walls might cause long term changes in the river bed and the sandy strand. The general dip of bedrock is towards the Mekong, and slope stability in the direction of bedrock dip (i.e. towards the Mekong) must be taken seriously. However, my brief did not extend to a formal consideration of this issue, and I have seen no documentation of any proposals.

12 Conclusions

In my view, it is desirable that the gabion wall should be constructed. Technically, it is the best solution for the site.

In the short term the appearance of the gabion construction will be out of keeping with the site, but it will rapidly mellow and merge in with the appearance of slopes above and to each side.

It is important that the gabions are founded on bedrock to control erosion at the foot of the slope.

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Appendix

Information on the geology supplied by Dr R. B. Stokes of Kingston University Geology department.

"I studied the geology of the area around Luang Prabang for about 3 days during a field season in November-December 1992 undertaken for Monument Resources (Overseas) Ltd. Descriptions and photographs of all the localities visited are included in an internal report for Monument. Monument relinquished their exploration licence in Lao PDR in 1998 and have no further interest in the proprietory data obtained.

The Luang Prabang area is of supreme importance as a heritage site - but not just for the architecture. Exposed in the banks of the Mekong in the Luang Prabang region are sites which are unique for palaeontological research (shell structure of fusulinid foraminifer was first established from material from Luang Prabang in 1906; Dicynodont reptile was discovered during the Pavie Mission in 1893 and more discoveries have been made recently; limestones in and around the town yield invertebrate fossils which are unknown elsewhere in SE Asia).

More relevant to your work is the possibility of instability in the bedrock of the town. My memory tells me of definite evidence of lateral movement on limestones in the town, and the probability of major thrusting having taken place as well. It is difficult to constrain the age of these tectonic events - but they may be quite recent in geological terms. They post-date what are undoubtedly Mesozoic strata and pre-date the Quaternary alluvium. They probably relate to tectonics which caused changes in the course of the Mekong and may thus be Quaternary.

I must confess that I have not followed this up in any detail as the work for Monument was to try and establish the stratigraphy with a view to correlations within their licence area (Luang Prabang was north of their acreage which only went as far as Sainabouli area)."