Stable Angles in Wellington Greywacke

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A method of determining stable angles in Wellington greywacke is outlined, and the accompanying graph gives a zone within which all variations of stable angles generally found in Wellington greywacke are expected to fall. Although the method is applicable to other regions, the graph is specific to Wellington.

IN Wellington the basement rocks are greywacke. These are highly indurated siliceous sandstones with beds of the indurated mudstones known as argillite. The sandstone members form more than half, and possibly as much as three-quarters, of the total bulk of the basement rocks.

The greywackes of Wellington are very intensely jointed so that their stable angles are rather low for rocks of such hardness.

A number of natural hillside and cliff slopes have been observed, and it is possible to give stable slope angles for various heights for the generality of Wellington greywackes. It is recognised that much of the topography of Wellington has been developed over a considerable time, and therefore, particularly in the case of the higher hills, the angle of the upper slopes will have been produced by erosional processes, such as soil creep and rill wash, which are independent of the strength of the rock. Slope angles produced in this way will always be less, sometimes considerably less, than the maximum stable angle. However, the range of angles measured will include slope angles at, or close to, the maximum stable angle. Because vertical faces have been observed, the stable angle is, therefore, that angle at which a slope of given height will remain for the order of 50 years or more. Because the slopes observed have been trimmed in recent times by sea or river it should not be assumed that there is any margin permiting increases of slope in engineering works designed to last only five to ten decades, particularly as the observed slopes will usually be freer of the factors that lead to rapid collapse. The highest natural face of vertical rock seen was 50 ft, the total height of the hill behind was 70 ft and the average slope for 70 ft was 75°. The steepest slope on a hill of 500 ft is 45° and as this is the natural angle of *rest* of a pile of loose angular blocks of hard rubble, it would appear to be a very satisfactory end figure. The accompanying graph is drawn from the observed angles and appears to allow for rock strength only in lower faces. The relationships between angle and height suggest that the effectiveness of rock strength decreases rapidly with increase in height. Vertical or near vertical rock faces are rare and never exceed a very few tens of feet in height. This absence of vertical faces will be due not so much to failure of the toe of the face under load as to the spalling off of loose blocks from the face. The diagram gives two lines; one, the extreme upper limit, will apply only to slopes in material with no planes of weakness at angles less than the batter angle, and the other is for intensely sheared rock where planes of weakness at many angles are present. Such an area is in a zone about half a mile wide from the Wellington Fault westward. Most areas will

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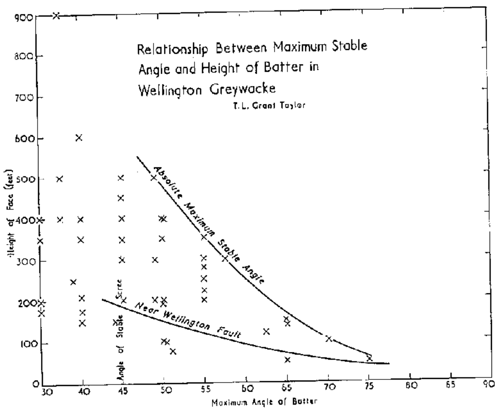

lie between these two extremes and each calls for an individual approach to determine the direction and inclination of shear planes if the cutting is of such height that a more precise batter angle becomes important.

Much of Wellington's greywacke has a moderately thick to very thick cover of weathered greywacke on the fresher rock. This cover has a high proportion of clay minerals and has very poor permeability, so that in wet weather it tends to swell and in extreme cases to slide. The worst hazard would be present in very heavy rain following an extended dry period on a slope when dehydration has opened wedges permitting wetting in depth. This weathered greywacke appears to have a considerable amount of internal friction, and providing the weathered material is in situ appears to be capable of standing in faces up to 30 ft and batters of 60°, and sometimes even more.

The degree of weathering to which the foregoing is applicable is considerable, and such that all the material except for quartz veins has decayel to an extent that expansion due to formation of clay minerals has led to closure of joints. The bulk permeability is small, with a coefficient of permeability of 10^4 to 3×10^4 compared with 10^4 for the Lyall Bay sand or 5×10^4 to 10^5 for the Hutt artesian aquifers.

The intensely weathered greywacke passes downwards into weathered greywacke where joints have been increased in size. At this degree of weathering the rock is still soft in that it can be cut with a knife at least in small lumps. The result is that at this degree of weathering, keying of joints is at a minimum and spalling from faces occurs to large degree. Batters in this material must be made quite considerable unless spalls can be prevented by some means such as plastering. In deeper cuttings, say more than 50 ft, the lack of coherence of the jointed mass will start to play a part and the diagram of batter angles will give relevant figures in the lower range of the graph.

Open jointing is characteristic, too, of the lower weathered zone even where the rock is too hard to cut or even break in the fingers, and the comments on spalling and stability are as relevant, but the middle range of the graph becomes relevant for stable angle because of superior rock strength.

The Hutt Road: The angle of the cliffs in this area appears to be about 50° to 100 ft, but because the promonotories are keyed at their foot by masses of unusually unsheared and less jointed greywacke this is not a general stable angle. The slopes above the cliffs are approximately 30°, but because of various processes of soil creep which have been operative, this angle will be lower than the maximum stable angle, which quite probably lies between the limits of 35° and 40° for 200 ft cliffs.

General Considerations for Stability: Most of the "greywacke" of Wellington is composed of alternating bands of argillite and sandstone, individual beds ranging from a fraction of an inch to many feet thick. There is a very great difference in strength between the sandstones and argillite and consequently the dip of the beds is very important in determining a stable angle. When the dip of the argillite is in the same direction as the batter, for batter heights of more than, say, 50 ft, batter angles must be always the same as or less than the dip. When the direction of dip of the beds is different from the inclination of the batter, allowance in batter angle must be made for the reduced strength of the argillite; this allowance may be as much as 10°. In the general case the dip of the rocks will be vertical and sandstone will form half or more than half of the rock. The absolute maximum stable angle can be read from the graph. This angle must be reduced to allow for jointing. The allowance made will usually be between 5° and 10° but may approach 15°.