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# The costs of housing developments on sites with elevated landslide risk in the UK

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**Abstract.** New housing targets are being set for local planning authorities resulting in more areas being zoned for development. There is currently no requirement for a landslide assessment prior to this zoning, and sites at elevated risk of landslides are being put forward for development without consideration of the additional costs and other impacts of building on these higher risk sites. This study aimed to reveal the increased financial, economic, social and environmental costs associated with these decisions. Case studies were focused on the city of Bath, an area of increasing population and “*one of the most intensely landslipped areas in Britain*”. The case studies found the financial costs associated with building in a landslide risk area to be significantly higher than the equivalent construction in areas of greater geological stability. Furthermore, it was found that uncertainty in cost when developing in unstable areas exacerbates this problem as the final cost cannot be accurately predicted before construction.

## 1. Introduction

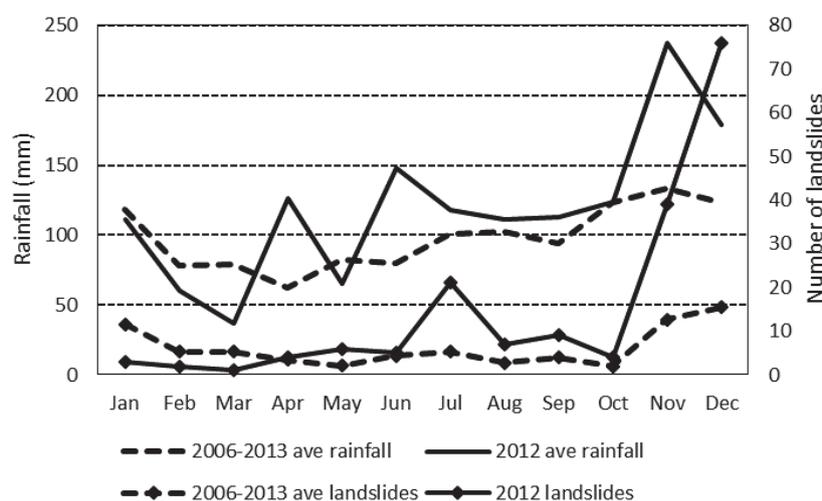
With a growing population, strict new housing targets are being set for UK local planning authorities resulting in more areas being zoned for development [1]. There is currently no requirement for a landslide assessment prior to this zoning, and sites at elevated risk of landslides are being put forward for development without consideration of the additional costs and other impacts of building on these higher risk sites.

There have been a numerous studies into landslides, particularly into the damage that they do to buildings and infrastructure and the casualties that result. There have been some studies into the costs of specific landslide events [2,3,4]. Rather than investigating the costs of landslide events as in these previous studies, this paper will explore the costs associated with building in a landslide area. These costs may be financial, economic, social or environmental affecting just individuals, a community or the whole economy. As well as being very damaging to the population, landslides can have a very detrimental impact upon buildings and infrastructure. Unfortunately, the occurrence of landslides in the UK is rising, with a total of 177 events in the UK in 2012 and thousands more worldwide [5].

The British Geological Survey (BGS) have analysed the data from the Met Office and concluded that the increased average rainfall and extreme rainfall events have led to a rise in the amount of landslides occurring in the UK [5]. The occurrence of landslides in the UK during 2012 is compared to rainfall



during the same period in Figure 1, showing there is a clear increase in landslides during or in the month following increased rainfall.



**Figure 1.** Rainfall and landslides in the UK (data from [5])

While the links between rainfall and landslides, and between landslides and damage to buildings and infrastructure are reasonably well established, data surrounding the increased costs of building in a landslide area is very limited. For this study, the increased costs were investigated through a series of case studies focused on the city of Bath, an area of increasing population and “one of the most intensely landslipped areas in Britain” [6]. Numerous options, including surveys, insurance quotes and case studies, were considered as potential methods to determine the costs that building housing in landslide prone areas had on costs. With surveys relying on responses from the general public who may not be aware of the issues, and insurance quotes requiring a high number of input variables to be assumed, it was decided that using case studies would be the most suitable approach. These case studies were based on the results from a series of interviews with industry experts and from data in geotechnical reports.

## 2. Development pressures and planning guidance

With rising UK Government pressure to build more housing there is also an increase in unsuitable sites being put forward for development and local councils may not have the knowledge and expertise to assess these sites. The main guidance paper surrounding the topic of developing in an area of mass movement was Planning Policy Guidance note 14 (PPG14) [7] which was removed from the public domain in 2012. Annex 1 of PPG14 further explored the guidance given and specialised it to the problems associated with building in a landslide area. It was therefore used by landowners, developers and Local Planning Authorities requiring assistance in identifying landslide areas. By restricting development in areas highlighted as a potential landslide risk, the impact of any mass movement in these regions would have been mitigated.

As already mentioned, PPG14 Annex 1 is no longer in the public domain yet it has also not been replaced hence leaving a large gap. Previous research warned of this in a discussion of the potential outcome of the planning system reformation and predicted that Planning Policy Statements (PPS) and PPGs with particular reference to PPG14, may be lost [8]. As a consequence it was suggested that this

loss of guidance would “*further diminish the degree to which planning controls can be used as a mechanism to control landslide hazards*” [2]. This has resulted in local authorities, landowners and developers having less certainty than initially anticipated. While it is possible for landowners, developers and local councils to obtain a landslide hazard report from the British Geological Survey (BGS) before any planning decision is taken, this is not required or even commonly undertaken even in some landslide prone areas. This leads to inappropriate planning applications, detailed studies and hearings which cost far in excess of the minimal cost of a landslide hazard report.

The Building Regulations for England and Wales specify that “*The building shall be constructed so that the ground movement caused by: (a) swelling, shrinkage or freezing of the subsoil; or (b) landslide or subsidence (other than subsidence arising from shrinkage), in so far as the risk can be reasonably foreseen, will not impair the stability of any part of the building.*” [9] This clearly relates to construction in areas of slope instability however, it is not preceded by an avoidance strategy. It is obvious that if construction in a landslide risk area is avoided, the associated problems of building in this area are mitigated. However, neither this, nor how to identify potentially problematic areas prior to a development proposal are discussed. Therefore, by the time construction is being considered or initiated it is normally too late for avoidance of unstable areas.

### 3. Geological context

The geology of Bath lends itself to be very susceptible to mass movement and in particular, the mixed nature of the limestone/mudrock sequence is of high engineering interest. There are three core groups of strata: Great Oolite, Inferior Oolite and Lias. These consist of strata types with varying soil properties and formation patterns, but the general section through the valley slopes in Bath are as in Table 1. The formations are gently dipping at 1-2 degrees for areas away from the valley slopes, although there is a major fault running through the Avon valley in Bath.

**Table 1.** Major geological units from top of hills to valley floor in the City of Bath [10,11]

Group	Formation	Approximate thickness (m)	Name
Great Oolite	Chalfield Oolite	10	Bath Oolite Twinhoe Beds Coombe Down Oolite
	Fuller's Earth	60	Upper Fuller's Earth Fuller's Earth Rock Lower Fuller's Earth
Inferior Oolite	Salperton Limestone	10	Inferior Oolite
Lias	Bridport Sand	60	Midford Sands
	Charmouth Mudstone	100	Lower Lias Clay

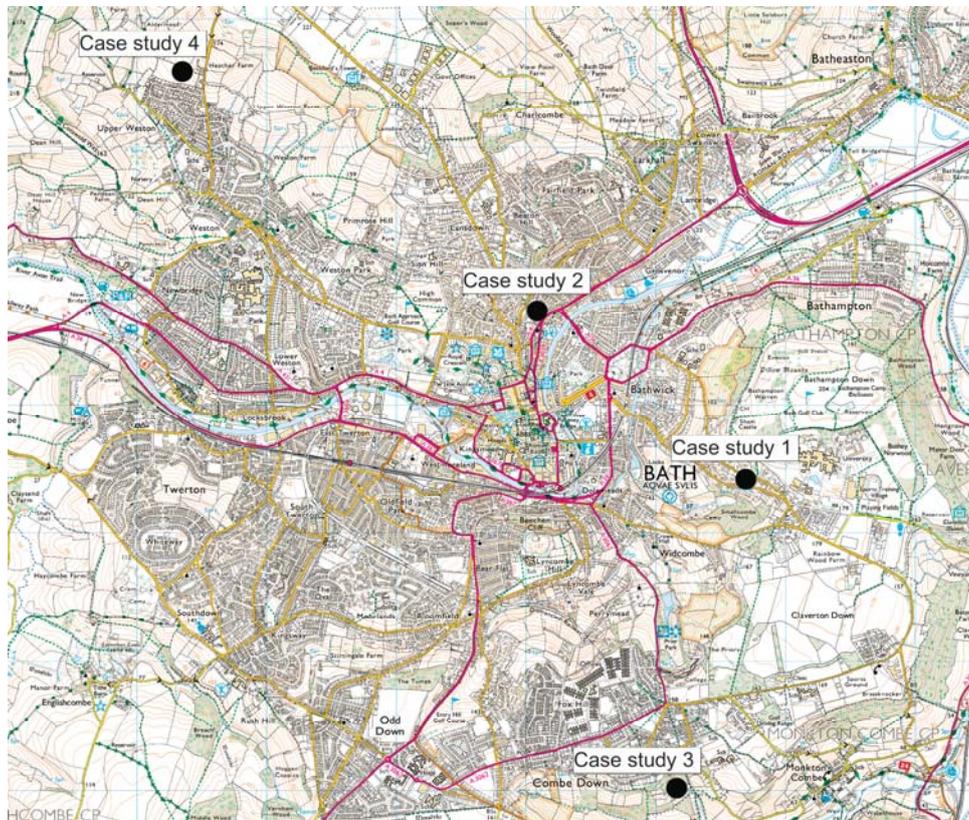
While there is some cambering within the Oolitic Limestones in Bath, the majority of slope stability problems are due to two of the weaker materials. The Fuller's Earth formation clays are of high plasticity and low shear strength [12] making this strata likely to move under local changes such as excavation or applied loads from construction. The Lias Group has also been widely studied due to its

relation to landslides [13]. Predominately, this group comprises of sandstones and mudstones with varying intermittence of limestone layers. This makes the group as a whole of much lower permeability than the Inferior and Great Oolite Groups sitting above it. This causes weathering of its upper layers, creating a region that is highly susceptible to slope stability problems.

#### 4. Construction case studies

Bath is considered a desirable place to live which naturally increases the demand for housing and has resulted in an average house price well above the national or regional average. As a result, there is additional financial incentive for developers to construct in areas at risk of landslides. The following case studies demonstrate the unpredictability of building in a landslide risk area and the accumulation of costs that slope instability problems entail. These case studies are considered on an individual basis prior to comparison and discussion. Due to a lack of ground investigations on the historic landslides and because the areas are now built up, it was not possible to obtain accurate cross sections through any of the landslides showing the location of the slip surface.

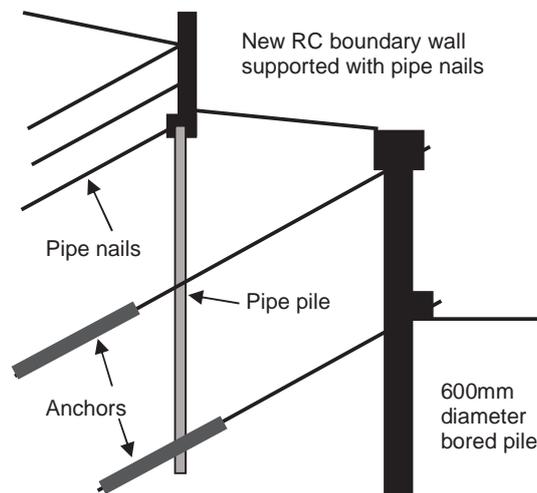
In all cases the principle was to mitigate the effect of the construction on local slope stability, rather than attempting to stabilise the slopes against future failures. In other words, the geotechnical design was to prevent the construction from inducing a landslide, rather than to stabilise an existing slope with marginal stability which is impossible in most cases because of the large marginally stable areas. The locations on the case study buildings are illustrated in Figure 2.



**Figure 2.** Case study site locations (contains Ordnance Survey information © Crown Copyright and Database Right 2015. Ordnance Survey (Digimap Licence))

#### 4.1. Case study 1

Constructed in 2008, and featured in the television series “Grand Designs”, this is a 5-bedroom home with internal floor area of 427m<sup>2</sup>. Numerous problems were encountered due to slope instability, typical of a building in a landslide risk area. Due to the potential slope stability problems, a raft slab was used as the foundation to form a platform for the house to sit on. Behind this a retaining wall structure was built using 60, 12m deep, bored piles in order to hold back the unstable slope above the site. The water presence between the permeable limestone and impermeable mudrock layers in the ground caused the drilled holes to collapse before the piles could even be installed. In order to overcome this problem, a casing had to be added to divert the underground water which added a significant cost that had not been anticipated. In addition the boundary wall with a neighbouring property had to be reconstructed as a reinforced concrete retaining wall, further reinforced with pipe nails. The final design is illustrated in Figure 4.



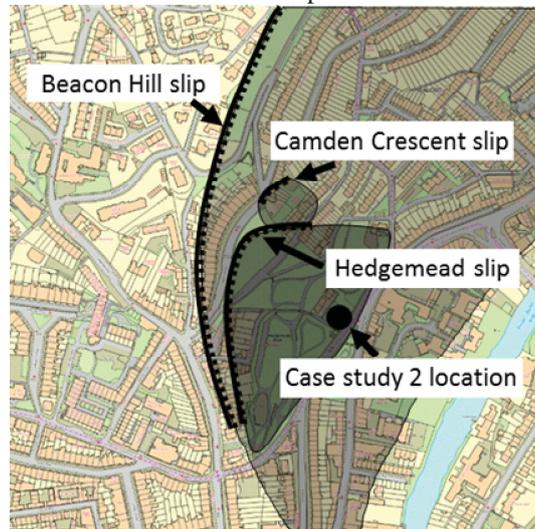
**Figure 4.** As built retaining wall for case study 1 (not to scale).

The initial cost estimations for the groundworks were approximately £300,000 but the actual cost was £385,000. The retaining wall required the installation of anchors as well as a deeper, more heavily reinforced structure than would be required in an area not suffering from ground instability. On top of this, a large capping beam was required which would not be required in a non-landslide area. Based on information from the groundworks contractor, the groundworks cost £265,000 more than in an equivalent construction in a non-landslide area [14]. The final groundworks have been stable to date.

#### 4.2. Case study 2

Case study 2 was for a separate extension to a furniture store showroom rather than a dwelling, but was comparable in size to a large dwelling (389m<sup>2</sup> internal floor area) and was across the road from the main furniture store location. The new extension was built in 2012 at the bottom of Hedgemoor Park, an area well known for its landslide risk. There were a number of previous landslides in the location as shown in Figure 5, with the most recent landslides being the Camden Crescent slip occurring during the construction of Camden Crescent in the 18<sup>th</sup> century, and the Hedgemoor slip occurring during the 19<sup>th</sup> century. The extent of the historic Beacon Hill is difficult to determine

because of the later landslides and because of the extensive construction over it, but this has been inferred from the mass movement deposits in the most recent BGS geological map [11].



**Figure 5.** Location of case study 2 with approximate location of nearby historic landslips [11,15] (contains Ordnance Survey information © Crown Copyright and Database Right 2015. Ordnance Survey (Digimap Licence))

As with Case Study 1, a reinforced concrete retaining wall and piled foundation structure with anchors was installed. The total costs for the groundworks was approximately £126,000 which the groundworks contractor estimated to be £81,000 more than would be the case if the construction in an area with low landslide hazard [14].

As with Case Study 1, the majority of the additional costs were from the construction of a retaining wall to provide a level base for the building and the installation of piles and ground beams instead of a shallow foundation system.

#### 4.3. Case study 3

The house for Case Study 3 was also featured in the television series “Grand Designs” and was constructed in 2009 as a redevelopment of an existing building with an internal floor area of approximately 400m<sup>2</sup>. It is set in the steep valley area of Combe Down and is an old industrial building on a plot of two acres. It took three years to achieve planning permission due to the area being of outstanding natural beauty, part of the green belt zone and a grade II listed property within the Bath World Heritage boundary. The original building consisted of two barns located on an ancient landslide which required a network of deep piles and steel reinforced concrete ring beams in order to stabilise both the slope and the structure. In order to alleviate the problem of land movement underpinning and consolidation of the footings of the building was also required.

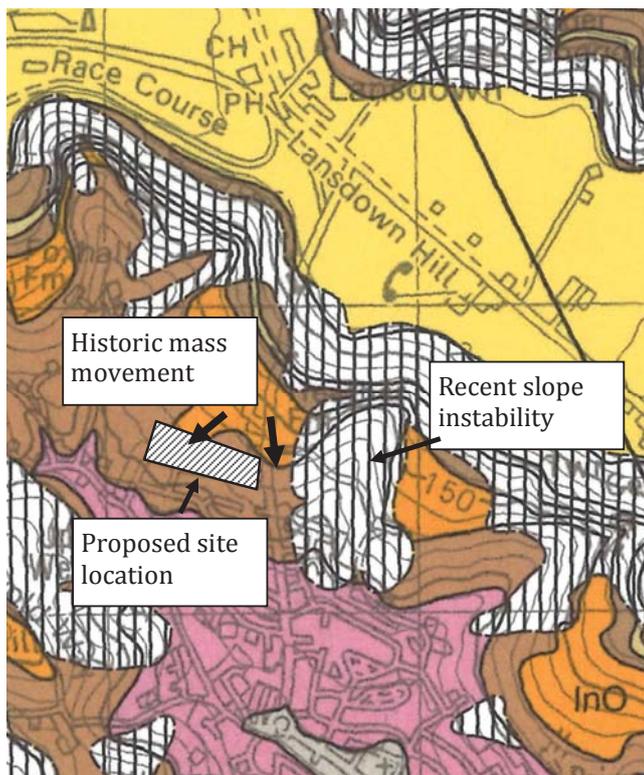
The total cost for these groundworks was approximately £70,000 which was an increase of approximately £30,000 compared to an equivalent new construction in a more geologically stable area. As this particular project was a retrofit rather than new construction, there is a possibility that no remedial foundation work would have been required had it been in a geologically stable area (as commonly the case for barn to housing conversions).

#### 4.4. Case study 4

Case study 4 is the only case study which has not been constructed, but relates to a proposed large area for development. The case studies previously discussed focus on the development of one building therefore it needs to be investigated as to whether, if conducted on a larger scale, it is feasible to develop landslide areas and include the required amount of affordable housing (typically 30% or more depending on the development).

Development of the site was originally to include 300 homes however, this was subsequently reduced to 150 [16]. Reasons for this may have included a change in site location and the slope instability problems highlighted by a geotechnical desk study of the area [17] which was only commissioned after objections related to slope instability were raised during the consultation phase for the Bath Core Strategy. It can be assumed that, although property size and style will vary, these homes will average three bedrooms in size. For a two storey, three bedroom home the recommended minimum floor area is 96m<sup>2</sup> [18].

The site is in an area of slope instability and has nearby areas where mass movement has occurred, including some landslips in the past 50 years, as shown in Figure 6.



**Figure 6.** Location of case study 4 with nearby mass movement (contains British Geological Survey materials © NERC 2011 and Ordnance Survey information © Crown Copyright 2011.)

The geotechnical desk study provided estimated costs surrounding the remedial works required to develop this site [17]. The investigation first categorised potential development areas into high, medium and low instability groups. In order to increase slope stability for development of the site the following measures were suggested:

- The installation of gravel filled shear trenches;
- terracing of the steeper sloped areas;
- retaining walls, most likely contiguous piled walls with a 5m retention height;
- piles in areas of medium and high risk.

Based on costs provided for these measures and taking the number of dwellings and area to be developed into account, the development of each dwelling in the low and high risk areas of the site will require between £27,000 and £37,000 extra groundwork costs in order to provide sufficient slope stabilisation. Prior to construction, a detailed site investigation would need to be undertaken to confirm the results of this desk study. The costs associated with this detailed site investigation would have to be added to the cost per dwelling.

This particular site was eventually rejected as suitable for development by the Planning Inspector, and it is therefore unlikely that this site will be developed in the near future. The reasoning by the Planning Inspector was related to visual impact and did not mention issues of slope instability.

## 5. Discussion

The case studies reveal a consistent increase of the construction cost in areas prone to slope stability failure, however the extent of this increase varies mainly due to site specific factors such as slope angle and immediate geology. Table 2 highlights this increase in cost through a comparison of the groundwork costs for the construction case studies detailed above.

**Table 2.** Additional groundworks costs for building in area at risk of landslides

Case study	Additional cost (£)	Internal floor area (m <sup>2</sup> )	Additional costs (£/m <sup>2</sup> )	Cost increase from construction in stable area (%)
Case study 1	265,000	427	620	220
Case study 2	81,000	389	208	180
Case study 3	30,000-70,000	400	75-175	75+
Case study 4*	26,000-37,000	96	271-385	271-385**

\* Each dwelling

\*\*Based on estimate £100/m<sup>2</sup> for foundations in non-landslide areas

This clearly indicates that construction in a landslide area is far more expensive than in a non-landslide area, but is still considerably less than the minimum of £600,000 for repair and stabilisation costs for the smallest landslide reported in one of the few previous studies on costs of landslides [2]. These results are particularly interesting, as they clearly demonstrate the consistent extra finances required to build on top of this natural hazard, whilst also highlighting the variation of this increase between the case studies. The individual case studies shows that there is a high level of variability and uncertainty in the final groundworks costs which could deter some developers. There was insufficient data to conclude whether the variability in cost was mainly due to different geotechnical design approaches or different landslide risk (ground conditions, slope angles and other contributing factors).

With the exception of case study 4 which involves a number of dwellings, the others were what could be considered high value applications (large houses / commercial premises with value around or over £1 million). A key reason for this is due to the most substantial cost being getting the required expertise and construction methods, such as a piling rig to site. Once the equipment is on-site replicating the process for more than one build is likely to be lower than for a single building.

It costs between £867.60/m<sup>2</sup> and £1323.60/m<sup>2</sup> to build a home, depending on the desired quality [19] and it can therefore be seen that the increase in groundwork costs experienced by the case studies is a large proportion of these overall construction costs. Specifically, the increase of up to £385 per m<sup>2</sup> for the large development (case study 4) is significant for an area where affordable housing was proposed.

This value is more than 75% above the approximately £220/m<sup>2</sup> extra over cost to take a 96m<sup>2</sup> 3 bedroom semi-detached home from the building regulations minimum to the Code for Sustainable Homes Level 5 requirements (the second highest level available) [20]. It was initially proposed that the development in the area for case study 4 and other areas proposed for redevelopment as part of the Bath Core Strategy was at the Code for Sustainable Homes Level 5, but the Planning Inspector removed this requirement as too onerous on developers.

## 6. Conclusions

Pressure from the Government to increase the housing stock in the UK is rising and this is shown through the extensive list of initiatives which continues to grow. These initiatives strongly encourage local authorities to increase housing in their respective areas. However, this is leading to unsuitable sites being zoned for future development as the previous guidance on developing in areas of slope instability in the UK was removed in 2012.

Although the final property value often outweighs the increased construction costs from building in a landslide prone area, the results from this study clearly show that, even if it is technically feasible, it is much more expensive to develop in a landslide prone area. This increase is due to a combination of extra design costs, installation of slope stability measures, the impact of mass movement during construction and reduced development area within a site as a result of the slope stabilisation structures and required spacing between homes.

There is a large variation between individual sites and the reason for this variation is primarily based on site specific factors which amongst others include the angle of the slope, surrounding properties, immediate geology (and geological features) as well as the weather during the construction process.

The construction case studies highlighted that the development of individual buildings in areas of mass movement may not be feasible for affordable housing however, for larger projects it may be possible to incorporate some affordable housing.

The costs of the construction in landslide prone areas can far exceed the extra over costs for building houses to the Code for Sustainable Homes Level 5 standard, and a decision should be taken on whether it is more in the national interest to construct in areas with increased risk of natural hazard, or build more sustainable buildings, particularly when the remedial measures for slope stability do not guarantee landslides will not occur in the future.

## 7. Acknowledgements

The information and assistance provided by John Peterson, Technical Director of Foundation Piling Ltd. Is gratefully acknowledged.

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