**Introduction**

In the 1700s, the stagecoach route from London (England) to Dublin (Ireland) was via the North Wales port of Holyhead. In view of the mountainous topography in North Wales, the road followed the coast, through Chester. With the increasing traffic in the early 1800s, ways of shortening this arduous journey were considered...
and Thomas Telford, subsequently known as one of Britain’s great civil engineers, was commissioned to examine the feasibility of creating a more direct route through Shrewsbury, Llangollen and Betws-y-Coed (Fig. 1). After overcoming some difficult engineering problems, 135 km of road between Shrewsbury and Bangor was opened in 1819 and continued as the main A5 trunk road until the 1990s.

Between Corwen and Betws-y-Coed, a 2.3 km stretch of the A5 is particularly twisty as the road passes through the gorge of the Afon Ceirw. Telford’s design involved the cutting of a ledge into the rocks along the northern side and, where necessary in the hollows, constructing high retaining walls (Fig. 2). While this 6 m wide road was acceptable for stagecoach travel, the sharp bends, with radii of only 30 m, did not meet modern requirements. The road had no verges and there was frequently a sheer rock slope on the northern edge (Fig. 3) and a 30 m drop into the river gorge to the south. In addition, with over 50% of the route between Ty-nant and Dinmael (Fig. 4) having a visibility of less than 70 m, the safe road speed was often no more than 20–40 kph.

In 1989, it was decided to make the North Wales coast road between Chester and Bangor (A55) the main route to the Holyhead–Dublin ferry and, in view of the engineering problems and the environmental sensitivity of the area, to make only selected improvements to the A5 to bring it up to modern road standards. On inspecting the highway at walk-over stage, there was considerable concern that a wedge failure could occur in the rock buttress 6–12 m above the road at the eastern end of the gorge section (Fig. 3). In addition, examination of Telford’s 10 m high retaining walls showed that in one limited area the slope below the structure had failed and undercut the toe of the wall, leaving the masonry unsupported.

Fig. 1 Location of the Glyn Bends section of the A5 London to Holyhead Road

Fig. 2 Part of the 200 year old retaining walls supporting the southern side of the original A5. Also seen is the lower part of a rock buttress present on the northern side (Fig. 3)

Fig. 3 Sheer rock face immediately north of the A5 trunk road
This paper describes the topographical and geological setting of the Glyn Bends section of the A5 and considers the evolution of the improvements. It also discusses the problems encountered during the construction, due mainly to the presence of thin volcanic ash bands within the strong Ordovician metasiltstones, which in this area form a southwards plunging asymmetric anticline. An important consideration was the visual impact of the new road in an area of open countryside, only some 10 km from the Snowdonia National Park (Fig. 5).

Topography

North Wales contains the highest land in England and Wales with peaks of over 1,000 m a.s.l., including Mount Snowdon (west of Betws-y-Coed), which rises to 1,085 m. In the Glyn Bends area, the relief is lower with Mwdwl eithin rising to 470 m and Foel Goch to 611 m, to the north and south of the A5, respectively. These hills form the watershed between the rivers draining westwards and northwards to the Irish Sea and those draining eastwards towards England. As a consequence, west of Corwen the A5 road passes up the valley of the Afon Ceirw, a tributary of the eastward-flowing River Dee, before descending towards Betws-y-Coed following the Afon Merddwr, a tributary of the northward-flowing River Conwy (Fig. 5). Although the watershed is not particularly high, the eastward-flowing rivers have eroded deep gorges as they descend from the almost flat-topped Cerrigydrudion Moor through the Lower Palaeozoic metasediments.

The River Ceirw meanders across the alluvial infill of a glacial valley, where the profile drops at some 1:50–1:60 to the west and east of Glyn Bends respectively (Figs. 4 and 6). In the gorge south of Pen-y-bont, however, the river falls 20 m in 350 m (1:18). Although the Ordnance Survey maps indicate waterfalls in this area, in reality they are a series of rapids which are most notable where the river falls 10 m in a distance of only 80 m. As seen from the contours, above the gorge the ground is more gentle and open in the area of Pen-y-bont.

When Telford designed his highway in the 1810s, in order to maintain a realistic gradient for stagecoaches he placed much of the road along the northern slope...
of the gorge in 6 to 12 m high cuts and built masonry walls where the road crossed small stream courses/hollows. In the Glyn Bends area, the road is some 30 m above the river level. Between the two main bluffs, the northern slope is more gentle, rising at circa 30° for approximately 40 m (Fig. 6). Above this, there is a 4 to 6 m high cliff, which in places is overhanging. As discussed later, the relief in this area has been created by a rock slide, which clearly pre-dates the construction of the road.

On the flatter area north of the gorge, there are several ridges almost at right angles to the river. It is likely that it is the presence of stronger, less fractured hence more resistant rocks which is responsible for the narrowness of the gorge and the main area of rapids discussed above.

**Background geology**

The primary mapping at the 1:63,360 scale was undertaken by Burke, Aveline and Ramsey and published in 1885. This remote area was not mapped again for over a century, but in the meantime, Alder had undertaken his doctoral studies in the area (1976) and the local authority had commissioned Webb to carry out some specific mapping in the Glyn Bends region. When the 1:50,000 geological map, including much of the work previously undertaken by Alder, was published in 1993, the road re-alignment scheme was out to tender; hence the modern map was not used in the initial planning and site investigation stage.

As can be seen from Fig. 7, the bedrock geology in the area is Lower Palaeozoic in age. The region was metamorphosed during the Caledonian Orogeny (Silurian–Devonian) and as a consequence the individual lithologies, frequently referred to in the geological literature by their sedimentary terms, from an engineering point of view behave as metamorphic rocks. The 1:50,000 map (Corwen Sheet 120, Fig. 7) gives the following stratigraphic succession.

**Ashgill series**
- Maerdy Mudstone Formation (up to 1,600 m) with the Rhiwlas Limestone (0–5 m) at the base

**Caradoc series**
- Tyn-y-glyn Mudstone Formation (0–2 m)
- Gelli-grin Calcareous Ash Formation (0–200 m) including the Cymerig Limestone
- Allt Ddu Formation (90–210 m)
- Glyn Gower formation (160–230 m)

The **Glyn Gower Formation** consists of well-bedded, laminated/cross-laminated muddy siltstones, siltstones and sandstones with spaced cleavage. Fossils are rare. At the top of the formation is the Frondderw Tuff formation (0–14 m), which consists of four sub-marine debris flows with the individual bands fineing upwards.
The Allt Ddu Formation includes siltstone horizons with a number of ash/tuff bands; the most prominent being the Garth Tuff. Some of these pyroclastic bands are sufficiently thick to form mappable units in parts of North Wales. In places, the siltstones are highly fossiliferous.

The Gelli-grin Calcareous Ash Formation is typically volcanoclastic material, which formed as an airfall accumulate in a marine environment. As well as containing occasional fossils throughout the main rock mass, a number of distinct fossiliferous horizons are present. At outcrop, such as seen along the A5 road cutting, the fossils have weathered selectively. The Gelli-grin also contains the approximately 6 m thick Cymerig Limestones, which consist of oval gravel to boulder-sized concretions of impure limestone, sometimes in a silt-rich matrix.

Although Alder had initially considered only one limestone horizon to be present in the Lower Palaeozoic strata of this area, subsequently two bands were identified and can now be seen at the western and eastern ends of the gorge. Although the stratigraphy of the limestones is difficult to distinguish, those in the west are now considered to be the Cymerig Limestones and those to the east the younger Rhiwlas Limestone, which is included within the Maerdy Mudstone Formation. These limestone horizons are particularly important, as karstic features have developed within them. Indeed, during the walk-over surveys, small cave systems were identified in the eastern part of the original road sections.

The Tyn-y-glyn Mudstone Member is less than 2-m thick, but was identified by Alder as a dark pyritiferous non-calcareous quartz-veined mudrock.

The Maerdy formation, which unconformably overlies the Gelli-grin, is typically a thick sequence of siltstones with some sandstone horizons. As mentioned above, the Rhiwlas Limestone generally forms the basal beds of this formation.

The Gelli-grin dips between 30 and 65° towards the south, although from the exposures it was noted that there was a 60° splay of orientations between N150° and...
N210°. In many outcrops, particularly in the siltstones, it is difficult to distinguish bedding from stress-induced spaced cleavage unless fossil horizons or minor lithological changes are present. In addition to the dominant cleavage, which dips northwards between 35 and 75°, there is a second sub-vertical set.

During the Quaternary, when the area was glaciated, large-scale removal of the weaker lithologies would undoubtedly have taken place such that in addition to the extensive area of till in the western part of the proposed route corridor, glacial deposits accumulated between some of the rock ridges on the flatter land above the gorge. With meltwater release as the thick glaciers were receding, intense erosion would have taken place, at least deepening the Afon Ceirw gorge.

While working for Clwyd County Council, Webb identified two areas of landslip. To the south west of Pen-y-bont Farm a small disturbance was located and 200 m to the south east of the farm, the hollow left by a larger landslip is evident both in the field and on the scheme contour map (Fig. 6). This slip, near the contact between the calcareous siltstone and the Rhiwlas Limestone, covers approximately 1,250 m². Upslope is a 4–6 m high rock face which in places overhangs and has clearly retreated by toppling failure since the main mass movement. On close examination of the base of the rock faces, a very thin band of weathered ash was identified in the northern extremity of this wedge-shaped hollow and hence it was considered that this section the gorge slope had failed along such a low strength band.

**Scheme design**

Improvement of the road between Ty-nant and Dinmael was necessary because of the

(a) extremely poor alignment, with the consequential restrictions on the safe, free flow of trunk road traffic;
(b) poor accident record, with the overall personal injury accident rate between 1984 and 1987 being four times the national average for this type of road;
(c) structural condition of the existing retaining wall supporting the A5 some 30 m above the base of Afon Ceirw gorge;
(d) potential instability of a wedge of rock at the top of the buttress seen in Fig. 3, part of which had already fallen.

As a serious failure of the retaining wall could close the road and there were no suitable diversion routes in this highland region, the Client considered the improvement of the road should be undertaken with the minimum of delay. The design was to comply with the Guidance Notes “Roads in Upland Areas” (Anon 1990) and for a speed of between 80 and 100 kph. However, the Authority emphasised the sensitivity of the natural environment, immediately adjacent to the Snowdonia National Park.

Initially five routes were assessed, four to the north of the gorge and one to the south. On environmental, constructional and economic considerations, the Tyn-y-glyn route was the most favourable (Fig. 4), having the least effect on the existing properties and involving no additional trafficking of the stone masonry arched bridge (Pont-y-Glyr-difffwys) across the head of the gorge.

The final horizontal alignment was chosen to

(a) optimise the distance from the A5 retaining walls to allow blasting to take place without unduly increasing the depth of the cut (Fig. 8);
(b) provide buttress support to the rock-anchored retaining wall east of Tyn-y-glyn, which had been built some years ago to support the highway;
(c) obtain a cut/fill relationship with an acceptable surplus, as disposal of fill would be easier and cheaper than importing additional material;
(d) provide a gradient and visibility for a design speed of 85 kph;
(e) limit the land takes and minimise the aesthetic intrusion of the new road into the existing environment.

Fig. 8 Schematic drawing showing the relationship between the new road cut and the original A5 supported by masonry retaining walls on the slope of the gorge
The improvement works included a 550 m long cut between Pen-yr-erw in the west (Ch 400) and the point where the new road would cross the existing A5 (Ch 950). The 7.3 m carriageway would be widened to 10 m in the eastern approach to the cut, to provide a climbing lane. In order to reduce the size of the cut and thus the impact of the road on the environment, this 10 m wide section of roadway had only 0.3 m hard strips and 2.15 m verges, which included a rock ditch and fence. Steep slopes were a key feature of the design to reduce land-take. East of Tyn-y-glyn, a high embankment was designed to reduce the gradient of the road, use much of the 0.25 million m³ of rock fill material generated in the cut and provide additional buttress support to the lower part of the hill in which instability had occurred in the past.

In view of the strength and lack of discontinuities in the metasiltstones, it was clear from the outset that any significant rock excavation would require blasting. It is well known (e.g. Hoek and Bray 1971; Matheson 1986) that unless pre-splitting is used the bulk blasting required to loosen and disintegrate the rock in the main excavation will disturb the strata behind the designed face. A decision was therefore taken to use a pre-split cut of 3:1 (72°) in the main cut. Above this, where overburden and weathered rock is present over part at least of the cut length, angles of 1:2 (26°) were planned (Fig. 9). However, the design guide “Roads in Upland Areas”, produced by the Welsh Office required that the highway should have as natural an appearance as possible. Consequently, rather than have a consistent straight/curved 3:1 pre-split face, the design included ledges in the 3:1 slope and some batters as steep as 4:1 (76°, Fig. 10).

An important consideration was the impact of the construction works on the existing major trunk road. While it was desirable to minimise interruptions to traffic flow, it was clearly important to protect road users from the shock of an explosion and, following each blast, to ensure both that the retaining walls were not affected and no fly-rock had broken the protection measure and landed on the road. As a consequence, blasting was generally permitted only once per day when the traffic flows were halted for some 20 min.

As seen in Fig. 6, the land rises to the north of the new alignment and from early analysis of the exposure data it was appreciated that the main geological structure is a southward plunging anticline. As a consequence, it was considered essential to undertake drainage of the rock mass, particularly north of the road, so that water flow would not be inhibited by the presence of low permeability ash bands. This could lead to a build-up of water pressures behind bands of low strength material at a time when the lateral constraint was being removed. In order to optimise their effect and minimise the visual impact, the permanent drains were designed with a fan configuration, permitting one collecting point for every five drains (Fig. 11). The collecting areas were to be recessed and hidden behind masonry walls built of site-won rock.

Site investigation

When the authors became involved in the scheme, a site investigation had already been undertaken under the supervision of Clwyd County Council. In addition to the intrusive investigation, discontinuity mapping of the exposures was undertaken and an interpretative report prepared. In view of the failure to the north of the existing road (Fig. 6), this earlier report had concluded that side slopes as low as 1:2 (26°) would be required, necessitating a very wide cutting in this hilly topography. Following the re-appraisal, a supplementary site inves-

![Fig. 9 Designed batter angles through the new rock cut at Glyn Bends](image)

![Fig. 10 Designed variations to the standard 3:1 batter to provide irregularity to the cut face ("monkey ledges"), thus reducing the visual impact](image)
tigation was considered necessary. The purpose of this investigation was to establish

(a) whether a 20–30 m cut could be safely constructed in this geological setting;
(b) if the rock blasted in the cut would form satisfactory rock fill;
(c) the nature of the glaciogenic deposits believed to exist at the western end of the cut and assess the maximum stable slope angle;
(d) whether the glaciogenic material excavated would form satisfactory earth fill or could only be used for landscaping;

Fig. 11 Details of the fan drains; plan section, collecting point and recessing

(c) the ground water regime and its significance for the short- and long-term stability of the rock and soil slopes;
(f) the nature of the material to the east of the cut on which the embankment would be constructed, in order to determine a safe batter angle;
(g) the thickness of Telford’s retaining walls to the south of the existing A5 and the nature of the fill between the walls and the bedrock.

After a detailed walk-over survey, during which all exposures were re-examined, a site investigation was designed which involved 29 trial pits (sometimes ex-
tended into trenches) and 15 rotary cored boreholes. Although the cutting was between 20 and 30 m deep, trial pits were considered necessary to establish the reason for the rock ridges referred to above and to inspect the nature of the near surface weathered ash bands such as that contributing to the historic planar failure indicated in Fig. 6.

In order to minimise fracturing of the rock due to the torque of the drill bit, 75 and 92 mm cores were obtained. It was considered essential for both the design engineers and the contractors to be able to appreciate the massivity or broken nature of the ground and hence, in addition to the total core recovery (TCR), solid core recovery (SCR), rock quality designation (RQD), fracture frequency (FF) and maximum core length (MCL), a pictorial profile of the discontinuities was included on the log sheets. Below the overburden level, the RQDs were generally in excess of 70% and at many levels there were 0–2 fractures per metre. For practical purposes, therefore, the visual fracture log was of considerable value in distinguishing the intact from the more fractured zones.

Initially, it had been intended to supplement the core logs with a visual inspection of the holes using CCTV, but the downhole conditions were not ideal. It was then decided to use a slim line geophysical logging technique, the dipmeter survey, in which the sonde is capable of measuring a number of formation characteristics including the radioactivity, the inclination of the strata and the orientation of the maximum dip, as well as the integrity (caliper log) and deviation of the hole. In view of the importance of locating weak horizons, which could be lost by drill flush, the caliper logging was particularly valuable.

In order to establish some shear strength values, samples were tested in the Hoek shear box. Figure 12 shows a typical result from a test carried out on a dipping discontinuity in the metasiltstones at 16.17 m in BH B66 which gave a $\phi$ value of 47°. In the same borehole, a 5 mm thick soft greenish grey clay with a greasy feel was recovered at 21.3 m. When a sample including this moist clay was tested in the Hoek shear box it gave a $\phi$ of only 14° (Fig. 13).

The trial pitting exercise along the line of the ridges confirmed the presence of faulting. At the top of the planar failure (Fig. 6), a trial trench exposed the low strength ash band on which the historic mass movement probably took place. Also seen were two discontinuities on which moist powdered metasiltstone closely resembled the ash band.

From the trial pitting exercise it was clear that the number of thin volcanic ash bands was likely to be more than even high quality coring would recover in strong inclined rocks as the weak material could easily be lost in the drill flush. As a consequence, it was decided that the contract would need to allow for changes in the design as the work proceeded, based on a continual re-assess-
the wall provided only a facing to the original slope while the upper part was used to retain the fill material. In some cases it was not easy to distinguish the superficial material from the in situ weathered bedrock in the horizontal holes. In the upper holes, the material was invariably a red brown gravel with much clay, which it was considered had been imported for the construction of the road. At lower levels, the recovered material consisted of more blocky gravel, cobble and boulder-sized metamudrocks with some red brown clayey seams; the open joints indicating this was probably in situ weathered material. The bedrock recovered by the coring included some light grey tuffaceous/ash material.

The horizontal and vertical drill holes indicated an irregular rock head profile, probably reflecting the change in topography seen elsewhere in the gorge. Some evidence of voiding was recorded during the drilling and on the CCTV survey. In addition the driller’s record showed cavities of 50–100 mm and in two instances a steel tape was inserted into the hole between drill runs for a distance of 1.5 m more than the drilled depth. As seen on the subsequent CCTV film, the cavities were narrow, linear features, probably representing open joints/fissures associated with the stress release of near surface rocks at the side of the gorge.

Failure of these retaining walls during the construction works would have created a major traffic problem in this part of highland Wales where the only alternative routes involve long detours. To reduce the impact of the necessary blasting, which could have produced significant distress to the retaining walls, the peak particle velocity was limited to 10 mm/s. In addition, a significant sum of money was set aside for monitoring during the works, including the provision of scaffolding to allow ready access to inspect the masonry.

**Construction**

It was appreciated from the outset that the upper surface of the main rock cut would vary significantly. The ridges running at approximately right angles to the river would require blasting from the existing ground surface while the glaciogenic materials in the hollows between the ridges could easily be dug by backactors. Invariably, the rocks were more shattered (Figs. 15 and 16) adjacent to hollows where faults existed and hence again could be easily dug using a machine with a rock bucket. In view of this anticipated variability, the upper part of the rock cut was designed to have an angle of 1:2, which in good material could steepen to 1:1.5 (Fig. 9). In the main rock cut, however, blasting would be required throughout and steep pre-split slopes would be formed as discussed above.

The pre-split for the main cut was drilled and fired in 9 m long panels. The drillers were specifically requested to record where the rocks were more shattered and whether the advancing hole passed through low strength volcanic ash bands. In addition, the advance of the presplit was restricted to 9 m ahead of the bulk blasting in order that the cut face could be inspected and a decision made as to whether the 1 m spacing of the pre-split holes should be reduced and/or the charge modified.

Brief details of the blasting parameters are given in Table 1. The vibration constraints stipulated during the design phase proved to be onerous, particularly where blasting was undertaken within 50 m of the walls. Indeed, in these areas, it was necessary to reduce the number of holes detonated, particularly in the pre-split panels, in order not to exceed the required ppv value. Although this often resulted in a reduction of the panel size, it is considered this approach was justified as the integrity of the walls was not compromised.

As there was some concern that the permeability of the rock may not allow effective de-watering using ver-
tical pumped holes, the excavation involved a “canal” cut (Fig. 17), which facilitated the installation of sub-horizontal drain holes, extending well behind the designed cut face. Installing these drain holes at right angles to the rock cut would ensure that there was no build-up of water behind the face prior to the construction of the permanent fan drains (Fig. 11) while maintaining the significant lateral burden necessary for an effective pre-split. The canal cut also had the advantage of allowing an inspection of the geology some 9 m in front of the designed northern face.

The contract specified that the excavation lifts should not exceed 6 m. This would allow visual assessment of the rock face and the installation of the designed stabilisation and any additional remedial measures, without having to use large hydraulic lifts as machines could operate from ramps of fill. In the area of the axis of the plunging anticline, however, (Fig. 18), there was concern that the north face may fail prior to the anchors being installed and stressed. Over this 150 m length, in the top part of the cut the mucking-out was reduced to 3 m lifts and stabilisation measures were undertaken before further deepening. In one location, however, some over-deepening did occur. A low strength horizon dipping into the cut at 30° was exposed and a planar slide took place (Fig. 19). Despite this failure, the cutting could still be accommodated within the existing land-take by omitting the narrow drainage berm at the top of the main rock cut, modifying the berm drainage design and undertaking some re-profiling. In addition, the overburden was netted to prevent coarse material moving across the smooth failure surface and ricocheting onto the road below.

This slip was high in the rock face and involved only some 200 t of material. However, as the excavation progressed, the anticipated low strength horizons were exposed (Fig. 20) at higher angles and at varying orientations to the cut face (Fig. 21). A decision was therefore taken to install 194 mm steel tubes set into 250 mm diameter holes with a cementitious grout (Fig. 22). These were subsequently increased to 300 mm as drilling tolerance was difficult to maintain in the inclined strata consisting of strong metasiltstones with weak horizons. These would act as dowels to retain the

Table 1 Details of the blasting at Glyn Bends

<table>
<thead>
<tr>
<th></th>
<th>Pre-split</th>
<th>Bulk</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purpose</strong></td>
<td>To form stable rock faces</td>
<td>Necessary for excavation of 0.25 million m³</td>
</tr>
<tr>
<td><strong>Drill holes</strong></td>
<td>Inclined (72°)</td>
<td>Vertical</td>
</tr>
<tr>
<td><strong>Hole diameter</strong></td>
<td>105 mm</td>
<td>105 mm</td>
</tr>
<tr>
<td><strong>Hole spacing</strong></td>
<td>0.85–1.0 m</td>
<td>2.5x2.5-m grid</td>
</tr>
<tr>
<td><strong>Blast ratio</strong></td>
<td>0.25–0.35 kg/m²</td>
<td>Fragmentation ratio ca. 0.45 kg/m²</td>
</tr>
<tr>
<td><strong>Vibration constraint</strong></td>
<td>10 mm/s (pv)</td>
<td>10 mm/s (ppv)</td>
</tr>
<tr>
<td><strong>No. of holes per delay</strong></td>
<td>3–10</td>
<td>Double and triple deck charges</td>
</tr>
</tbody>
</table>

Fig. 16 Rock face to the west of Fig. 15 showing one of the ridges referred to in the text

Fig. 17 Schematic diagram showing excavation phases

Fig. 18 Photograph of the south face showing the southerly plunging anticline
slope until the appropriate long-term stabilisation measures could be installed. Along part of the 150 m of cut, two rows of 10 to 12 m long dowels of 12.5 mm wall thickness were installed in the 6 m wide berm at 1.5 m centres, off-set at 1.5 and 3.5 m from the cut line. In other areas, this was reduced to one row at approximately 4 m centres. The decisions were not based solely on mathematical analyses but were very much an engineering judgement in this specific site situation where the rock face was to be excavated by pre-split and bulk blasting. In addition to ensuring the short-term integrity of the works, there was a need to consider the safety of personnel working below the face.

It was appreciated that the firing of the pre-split and bulk blasting in the main cut would damage the cement grout around the dowels. To restrain the dilation/uplift of the rocks when the blasting took place, a rock bolt was installed within the dowel tubes such that a restraining plate could be fixed at berm level (Fig. 22). The installation of this form of dowel generally proved very successful in supporting the rocks in the main cut beneath the berm level during the subsequent excavation phase, prior to the installation of the permanent anchors (Fig. 23).

The working loads for the mono bar anchors were determined as 400 and 600 kN; their generalised elevations and inclinations are shown in Fig. 23. In the case of the upper batter, the fixed lengths were placed behind a line projected at 1:2 from the back of the intermediate berm. The upper row of anchors in the main cut was also placed behind a 1:2 line projected from the rock catch drain. The middle and lower anchors, however, had fixed lengths at least 8 m behind the cut face so as not to over-stress the rocks in the slope. A total of some 4,500 m of anchors was installed in the cutting, inclined at between 10 and 15° to the horizontal.

The geological mapping of the face and interpretation was ongoing throughout the construction period (Fig. 24). Most of the strata were strong to very strong metasiltstones although some limestones occurred; the boundary between the two lithologies being gradational. The volcanic ash bands exposed varied in thickness between 50 mm and 1.3 m. In some of the thicker bands, there were pipe-like sedimentary flame structures and in some cases, crystal growth slickensides were present—evidence of slow tectonic movement in a wet, chemically saturated environment.

As the cutting was developed, clear evidence of an open fold was observed (Fig. 18). The general structure of the area between Ch 650 and 950 is shown in Fig. 25, where it can be seen that the crest of the anticline occurs at approximately Ch 820 and the hinge of the adjacent syncline at approximately Ch 740. The folds plunged in a southerly direction between 20 and 30°. As a consequence, to the east and west of the main anticline and syncline the bedding
was generally perpendicular to the design face (Fig. 16). However, between Ch 780 and Ch 900, the strike gradually swings round to a more easterly direction (Figs. 20 and 21) making the face more susceptible to wedge-type failures when intercepted by joints or faults.

The faults crossing the area can be separated into two sets. Strike/slip faults orientated in an east-west direction are near-vertical and have crystal growth slickensides up to 30 mm in thickness. These east–west structures often occurred at a short distance behind and effectively parallel to the cut face. The second set were also high angled but with a north–south orientation. As such they were generally perpendicular to the design face and had little effect on the stability.

As discussed above, in order to minimise the visual impact, “monkey ledges” and steepened excavations were to be cut at the positions shown on the drawings, unless on site inspection indicated that these positions were inappropriate. In view of the considerable structural disturbance of the rocks in which the pre-split took place, however, the need to create irregularities was limited.

On-going monitoring was undertaken on the high retaining walls on the south (gorge) side of the existing A5 road using scaffolding erected along their entire length. After each blast, the walls were checked to ensure...
the integrity of the road prior to the highway being re-opened to traffic.

This paper has concentrated on the northern side of the cutting as this is where the main problems were anticipated in view of the southerly dipping anticline. The berm on the southern side was narrower and less remedial work was undertaken as the inclination of the strata is into the face. However, as noted above, some of the discontinuities, both joints and faults, run effectively north west/south east (parallel to the road in one area) and hence bolting was required. A typical example of such a joint is shown in Fig. 26.

Figure 27 shows the northern slope of the completed road through the rock cut. At the western end, where the cutting was through glaciogenic deposits, the designed slope of 1:1.75 was satisfactorily created with no major difficulties. Slope drains were installed as springs were known to exist, emanating from the buried rock surface. The embankment to the east of the rock cutting was constructed mainly using the 0.25 million m$^3$ of site-won rock fill and covered with a veneer of glaciogenic material, generally at an angle of 1:3.

**Summary**

The new rock cut at Glyn Bends on the A5 in North Wales was undertaken to alleviate the difficult conditions where this major trunk road passes through a gorge up to 40 m deep. When the road was constructed some 200 years ago, rock cuts were undertaken to create...
ledges along part of the gorge while in other areas the 6 m wide road was supported by up to 10 m high retaining walls.

The Glyn Bends area, between Corwen and Betws-y-Coed, is close to the Snowdonia National Park—an area of outstanding natural beauty. As a consequence, the client and designers were very concerned to create a realignment which was in sympathy with this upland environment.

The strata through which the main 550 m long, 25 m deep rock cut was created were mainly Ordovician. These rocks were metamorphosed during the Caledonian Orogeny hence the main lithologies in which the cut was undertaken were metasiltstones with two limestone horizons. In addition, some volcanic ash bands within the Ordovician strata formed weaker horizons, in which crystal growth slickensides had sometimes developed. Near the surface these ash bands had often weathered to form horizons with low shear strengths.

In this area, the Caledonian Orogeny imposed an open fold structure, with an anticline and syncline exposed in the cut. The folds plunge southwards such that the strata dip out of the high northern face.

In view of these difficult ground conditions, it was particularly important that the exposed geology was mapped and ongoing assessments made. For this reason, the Deputy Resident Engineer had a geotechnical background and an engineering geologist was on site full-time during the excavation of the rock cut.

The design took account of the fact that adjacent to the high rock cut the existing A5 was supported by an anchored wall over an area where movement had occurred in the past. To protect the longevity of this old, already anchored wall and to produce an acceptable grade to the new road, a high embankment was built from the 0.25 million m³ of rock taken from the cutting.

The design involved 4,500 m of anchors as well as extensive drainage of the steep 3:1 pre-split cut slopes. In view of the planned stabilisation measures and the likelihood that some additional work would be required, the excavation lifts were restricted to 6 m (to provide access) and 3 m in the sensitive zone near the axis of the anticline. Despite this, a small amount of overdig caused slope movement, emphasizing the significance of controlling the depth of dig and the timely emplacement of anchors and drains.

Although the minor slip in the upper cut face was accommodated without the need for further land-take, some additional strengthening of the lower slope was considered necessary before the cut was extended below the main berm. It was therefore decided to install a series of 10 to 12 m long dowels through the northern mid-slope berm to reduce the possibility of rock sliding when the final cut was undertaken. By placing a bolted anchor into the dowels, it was also possible to restrict uplift/dilation which could cause the rocks beneath the berm to become loosened during the blasting due to lack of vertical load. These dowels also made a positive contribution to the overall stability of the rock slope.

A vibration constraint of 10 mm/s was imposed and this, coupled with ongoing inspection, ensured that the integrity of the adjacent 200 year old retaining walls was not compromised.

In order to reduce the visual impact of the cutting the design included variations on the cut angle and the creation of irregular “monkey ledges”, particularly on the higher northern slope.

This paper discusses the investigation and design philosophy and highlights some of the constructional activities undertaken to create a significant cut through at Glyn Bends North Wales.

Acknowledgements The authors wish to thank the Director of Highways, National Assembly for Wales, for permission to publish this paper. Any of the statements or comments made above should be regarded as personal and not necessarily those of the National Assembly for Wales and constituent part or connected body.

References


Hoek E, Bray JW (1971) Rock slope engineering. Inst Mining Metall Lond