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Stability and Collapse, Old Man of the Mountains, Franconia Notch, New Hampshire

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Key Terms: ***Old Man of the Mountains, Rock Mechanics, Rock Mass Stability, Geologic Landmark***

ABSTRACT

On May 3, 2003, the Old Man of the Mountains natural rock profile collapsed, resulting in the unfortunate loss of the official emblem of the state of New Hampshire. A systematic reconnaissance of its stability had been performed in 1976 by the New Hampshire Highway Department as part of the environmental impact statement for Interstate 93. This reconnaissance estimated the Profile's in-place stability and its capacity to withstand blasting vibration from below. The work showed that 1) the dead weight of the Profile's blocks cantilevered at their combined point of bearing created a delicate stability; 2) the Profile from the nose up was relatively more stable than from the upper lip and chin down; 3) the Profile was subject to toppling collapse if natural processes or dynamic stress disturbed it; and 4) blasting could take place beneath it if no vibration in excess of those in the ambient natural environment was allowed to reach the rock mass. Careful blast monitoring during construction of Interstate 93 between 1985 and 1986 showed this vibration objective was achieved. Most recently, estimates of the mechanism and cause of the Profile's collapse suggest it was a progressive toppling failure initiated by a sudden loss of intact compressive strength in the granite immediately beneath the point of bearing of the cantilevered chin. The granite's intact strength had been naturally compromised over time by kaolinization decomposition and freeze–thaw degradation.

INTRODUCTION

On May 3, 2003, the Old Man of the Mountains natural rock profile (the Profile; Figures 1 and 2 and Table 1) collapsed and fell about 250 m (825 ft) onto the talus slope along and about 270 m (900 ft) above Interstate 93 (I-93) in Franconia Notch, 120 km (75 mi) north of the state capital of Concord (for contemporary photographs, see Reed, 2003; Wunsch and Fowler, 2004). The collapse resulted in the loss of a famous geologic landmark and the official emblem of the state of New Hampshire. This natural event brought to a close an often sublime, nearly 200-year relationship between the people of New England and the Old Man, a relationship characterized by remarkable human effort to understand how it formed, the mechanism of its stability, ways to secure and preserve it, and how to embrace the humanistic and philosophical significance of its natural, but utterly human, profile (e.g. Hawthorne, ca. 1840). This article summarizes the results of the various geotechnical activities that have taken place on the Profile over the past 198 years, with particular attention to those of the past 28 (Schile, 1975; Fowler, 1982; Fowler, 1997). Table 2 provides a convenient historical summary readers are encouraged to review before proceeding further (from Fowler, 1997).

As shown in Table 2, for more than 100 years and up to the mid-1970s, these geotechnical activities were undertaken by private individuals relying on limited, mostly personal resources or by fiscally limited governmental initiatives. In the mid-1970s, this changed when greater but indirect funding became available through public works projects located near the Profile (e.g., I-93). But over the years, no substantial funding was ever provided for the study of the Profile's stability or long-term security. Remarkably, it was feared by those in position to appropriate such funding that field implementation of preservative schemes developed by such studies might themselves endanger the delicate security of the important landmark. As a result, no formal or systematically rigorous geomechanical study of this complex rock mass was ever made. As so often true with case histories like this, the observations, conclusions, and recommendations reported have been constrained by the nature of study permitted by available funding.

Geologic Structure and Mechanics of Stability

In 1976, at the request of the Federal Highway Administration, the New Hampshire Highway Department (now the NHDOT) directed the author (then an employee) to conduct a systematic reconnaissance of the structural geology and basic rock mechanics of the Profile. The work was conducted in conjunction with the preparation of the draft environmental impact statement (EIS) for I-93 and its various alternatives through Franconia Notch, between

Figure 1. Old Man of the Mountains from Profile Lake, Franconia Notch. Viewpoint about 600 m (2,000 ft) north and 550 m (1,800 ft) below (photo by author, 1976).

Table 1. *Dimensional information rock mass of the actual Profile.*

Height	13.7 m	± 45 ft
Width	9.1 m	± 30 ft
Thickness	19.8 m	± 65 ft
Volume	2,470 m^3	± 87,200 ft^3
Weight (mass)*	6,530 tonnes	± 7,200 tons

*25.9 $kN/m^3 = 165\ lbs/ft^3$.

Lincoln and Franconia, NH. It was prompted by general concern about the possible effects that the several design and construction alternatives for the highway might have on the well-known landmark, the overall stability of which had been a matter of considerable concern during the planning process. The purpose of the reconnaissance was to measure and document, for the first time, the actual dimensions and structural relationships among the blocks comprising the Profile; to make a systematic estimate of their composite stability; to estimate ways in which dynamic stress, such as that from construction blasting, might affect the rock mass; and to make recommendations for the security of the Profile during the proposed construction below. The 10 weeks of summer field and office work were carried out by geologists and engineers of the NHDOT who were also experienced rock climbers.

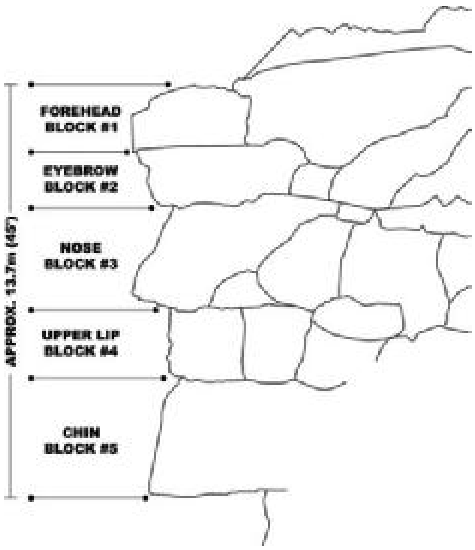

Figure 2. Diagram of Profile's component block combinations.

Most earlier work on the profile concentrated on the stability of the partially separated, obviously unstable forehead block and the smaller blocks on its surface (Table 2: 1916 and 1958). However, nothing had been done regarding the blocks underneath, which were critical to the stability and security of the Profile. Work by Schile (1975) suggested for the first time that the state of static stress in the rock mass as a unit, and in these lower blocks in particular, might be delicate and that detailed dimensional and spatial information was needed for more complete analysis. The work described here started where Schile's work left off and resulted in a rudimentary but, as events would show, fairly accurate description of the mechanism and state of stability of the Profile.

The Profile and each of the uniquely shaped blocks comprising it were formed by fortuitous weathering and selective breakage along five discrete sets of structural features (joints, fractures, and a shear zone) in its rock mass. Figures 2–5 and Table 3, respectively, illustrate and identify these features. Set 1 included all of the joints in sub-horizontal planes that cut through the rock mass and that were selectively fractured on their easterly edges to form the Profile view (Figure 2). Set 2 included the sub-vertical joints along which breakage had occurred to create the cliff face south of the Profile, while Set 3 included the sub-vertical joints along which the cliff was formed north of the Profile (Figure 3).

Set 4, which included only one joint, was located such that it represented the likely cut-off joint on the easterly side of the blocks making up the Profile. Set 5, again containing only one joint, represented the south face of the Profile, and Set 6 represented the north face of the Profile's rock mass. Selective breakage along these last three sets (4–6) was responsible for the distinctly triangular shape of the chin and upper lip blocks (Figure 4) which, as will be discussed later, were critical to the support mechanism of the Profile. Set 7, which was not directly part of the Profile,

Table 2. *Chronology of human involvement and geotechnical activities on the Old Man of the Mountains.*

Date	People and Events
1805	First recorded sighting by surveyors scouting road locations in Franconia Notch.
1828	Gen. Martin Field publishes first widely distributed article on the remarkable Profile and its sublime implications.
±1840	Nathaniel Hawthorne publishes his famous short story, "The Great Stone Face."
1853	The elegant Profile House is built near the present location of the Cannon Mountain Tramway. Its owner caters to patrons seeking inspiration from the Profile, and he declares its preservation to be vitally important.
1872	The Appalachian Mountain Club and a Boston newspaper of the day collaborate on a comprehensive article about the Old Man, including its apparently delicate structure.
1906	Rev. Guy Roberts of Whitefield begins a one-man, 10-year campaign to convince the local town fathers (the Notch belonged to the Town of Franconia then) to take some measures to secure and preserve the Profile.
1915	Rev. Roberts arranges a field meeting on the Profile with E. H. Geddes, an expert granite quarryman from Quincy, MA, and several local officials. Geddes agrees to furnish his expertise to "secure the rock mass" to preserve it; the local officials approve, but work is funded independently by Roberts and Geddes.
1916	The first short, 25-mm (1-in.) tie rods are installed with hand-drilling techniques by Geddes on top of the forehead slab to prevent its pieces from sliding or rolling off and upsetting the "center-of-gravity relationships" (all these devices remained in place until the collapse in 2003).
1928	Franconia Notch State Park is established by the New Hampshire Legislature.
1937	Geddes revisits the profile to check his earlier work. He decides to install several additional tie rods, seal over several cracks where water seeps between the slabs, and add several poured-in-place cement blocks to provide baselines for detection of incipient movement between the slabs.
1945	New Hampshire Legislature makes the Old Man of the Mountains the official state emblem.
1954	State Geologist Ralph Meyers, Prof. Donald Chapman (UNH), and Director of New Hampshire Parks Austin Macauley make an official visit for the Legislature and report the Profile is very unstable, in spite of the good work done on top of the forehead slab. They recommend detailed study of the blocks beneath to determine the Profile's true state of stability, its security, and thus its longevity.
1958	After much discussion (stimulated by fear the Profile might be so delicate that doing anything might knock it down) a series of long, 76-mm (3-in.) turnbuckles are installed, this time with mechanical drilling equipment, between the two largest pieces of the forehead slab to keep the front portion, with its perched crest block, from sliding off the profile. Strain gauges are mounted on the turnbuckles to begin the first geotechnical monitoring on the Profile, but no reinforcement investigation or related work is undertaken on the critical blocks beneath, despite the 1954 report. Neils Neilsen and his staff at the Bridge Maintenance Div., NHDOT, begin their annual inspection and maintenance program that continued each year until the summer of 2002.
1965	General reconnaissance and natural-background seismic investigations of the Profile are made by NHDOT consultants and the U.S. Geological Survey, respectively, for I-93 planning. They find wind to be a frequent source of substantial vibration (particle velocities up to 12 cm/second or 5 in./second) but conclude construction can proceed beneath the Profile, "if carried out very carefully," with blasting vibrations kept as far as possible below these ambient natural levels.
1975	Dr. Richard Schile, Thayer School of Engineering–Dartmouth College, and his students undertake the first field reconnaissance of the blocks beneath the forehead. This work is hampered by the inability to obtain accurately reproducible dimensions on the blocks comprising the rock mass while suspended from climbing ropes, and their mechanical calculations are not completed.
1976	Roger Martin and Brian Fowler (then civil engineer and engineering geologist, respectively, for the NHDOT) solve many of these rock-climbing problems and, with photogrammetric help through the I-93 EIS, finish the field work started by the Schile team and complete the first rudimentary structural–mechanical analysis of the Profile's support mechanism and state of stability. The study suggests construction can take place beneath the Profile if vibration reaching the rock mass is restricted by careful blasting design to the smallest fraction possible of the ambient natural levels observed in 1965.
1980	Franconia Area Heritage Council publishes *Saving the Great Stone Face,* reviewing the history of efforts to preserve the Profile to that time (Hancock, 1980).
1982	Results of the 1976 study are published (Fowler, 1982).
1985–1986	Construction of the I-93 Parkway in the Notch and beneath the Profile is undertaken and completed with no damage observed and no blasting vibration of more than 5% of ambient natural levels recorded at the Profile's rock mass.
2003	Profile collapses May 3.

included (and still includes) a narrow fault-bounded shear zone that represented the structural geologic reason the Profile was allowed to develop on the cliff.

The significance of Set 7 in the formation of the Profile was most interesting (Figures 3 and 5). The faulted shear zone at the junction of the south face of the Profile and the cliff face and a similarly oriented zone about 15 m (50 ft) to the south (Figure 6) are major structural features in the rock mass of the cliff. Shearing movement within Set 7 appears to have been a combination of linear and twisting displacements that resulted in a net rotation that, as can be seen in Figures 3 and 5, changed the orientation of the sub-vertical face-making joints north and south of the Profile from N20E to N35E (Sets 2 and 3).

This change was fortunate for the Profile's development because the resulting sub-horizontal dip of joint Set 1 was

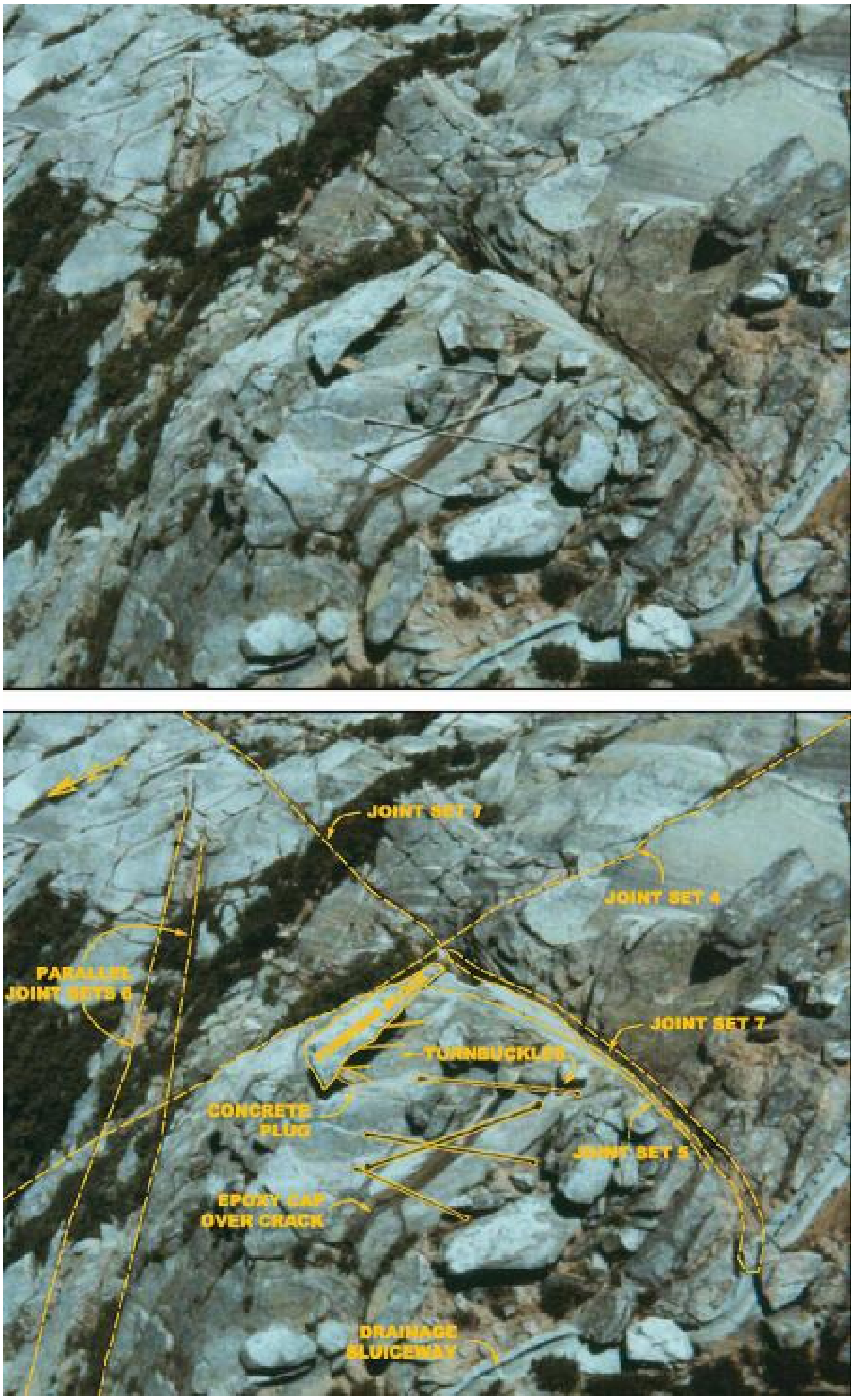

Figure 3. Profile's rock mass from about 30 m (100 ft) overhead (top) and overlay view showing important structural geologic and man-made features (photos by D. Hamilton, 1976).

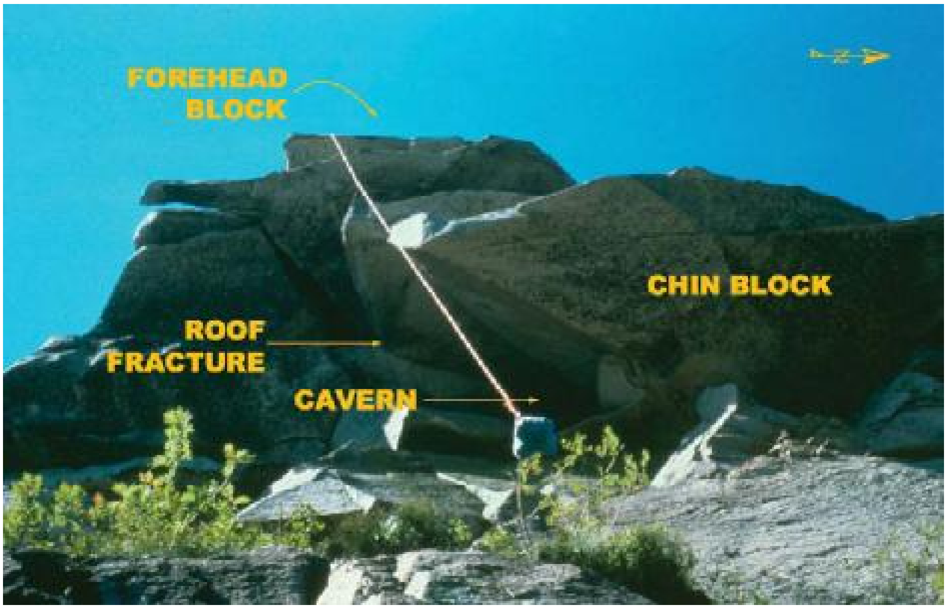

Figure 4. Profile's rock mass from about 25 m (82 ft) directly beneath (photo by author, 1976). Note location of the cavern and the fracture in its roof that separates the roughly triangular-shaped and delicately cantilevered chin and upper lip blocks from the rest of the rock mass.

then rotated slightly into the plane of the cliff north of this zone instead of nearly parallel to the plane of the cliff south of the zone. If this reorientation had not occurred, the dip direction of joint Set 1 would have been sufficiently parallel to the cliff face so the Profile's rock mass would have fallen away long before the Profile could have formed as the combined cliff-forming processes of weathering and freeze–thaw cycling proceeded.

At the time of this reconnaissance in 1976, before today's easy availability of desk-top kinematic analysis and finite-element software, this formation hypothesis was found to be well supported using a simple structural analysis that estimated the optimum strength-mobilization direction in the bulk rock mass. The technique (since replaced by more modern methods) is a derivative of the still-useful friction-circle concept as described by Goodman (1976). It is illustrated in Figure 5, where circles have been drawn around the main pole to the average plane of each structural-feature set. The radii of these circles are equal to the estimated angle of internal friction for the granite comprising the profile (35 degrees). According to the technique, the shared area common to the greatest number of circles represents the orientation at which the greatest strength is developed within the composite rock-mass configuration. In the case of the Profile, this direction was N23E, 45NW.

Thus, because the most important joints (Set 1) dipped back into the cliff in the general direction of this optimum strength-mobilization orientation and because the composite rock mass had not collapsed, it appeared likely its bulk center of gravity was located somewhere just behind the junction of the lower cliff and the Profile with its point of bearing likely located beneath the supported portion of the chin, as illustrated in Figure 7. Thus, the Profile's composite rock mass was precariously cantilevered in position by its own dead weight. The security of this mechanism was, however, clearly delicate because of the very precariously cantilevered configuration of Blocks 4

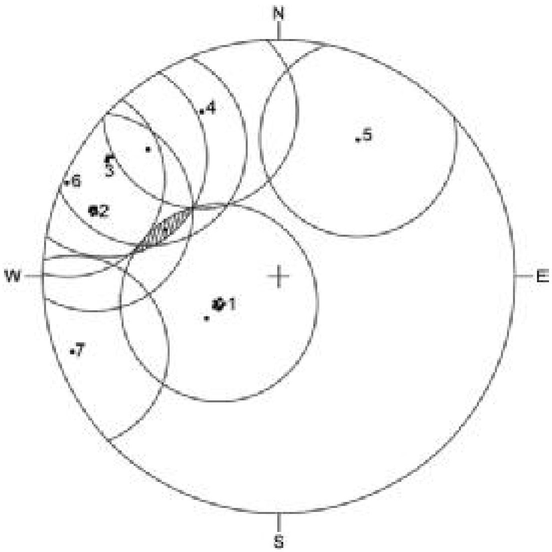

Figure 5. Pole diagram of structural features (lower hemisphere). Set 1, sub-horizontal joints through Profile's blocks. Sets 2–7: sub-vertical joints defining the cliff face south of the Profile (2), the cliff face north of the Profile (3), the cut-off joint east of Blocks 2–5 (4), the south face of the Profile (5), the north face of the Profile (6), and the shear zone south of the Profile's rock mass (7).

Table 3. *Average orientation of structural feature sets of the Old Man of the Mountains.*

Set	Strike	Dip
1	N25W	23NE
2	N20E	75SE
3	N35E	80SE
4	S65W	73SE
5	N60W	60SW
6	N25E	Vertical
7	N20W	85NE

and 5, and it was clear that only a minor redistribution of the stresses developed by the configuration might precipitate the collapse of the rock mass. With this in mind, three principal conclusions were drawn at the end of the reconnaissance and basic analysis.

First, based on the dimensional and spatial data and the rudimentary mechanical analysis, the cantilevering mechanism of the Profile's in-place stability was postulated as illustrated in Figure 7.

Second, from the analysis and field observations, the intersections of the joints in the sub-vertical plane at the rear of the Profile's composite rock mass suggested the likely rearward cut-off joints for Blocks 1–3 were located sufficiently into the mountainside behind the center of gravity of the composite rock mass so the relative stability of their comparatively broad flat blocks was greater than that of the more blocky, triangular, and extensively overhung Blocks 4 and 5 below. These two blocks instead were cut off from the rest of the rock mass by the cavern and fracture extension behind them (Figures 4, 6, and 7) and thus appeared close to toppling collapse. If this were to occur, given their direct involvement with the likely foundation (point of bearing) of the composite rock mass, the subsequent toppling of Blocks 1–3 would quickly follow once their combined weight was unsupported from below.

Third, because the Profile had survived substantial vibration during the earlier drilling and was currently surviving significant ambient vibration from wind (Table 2: 1958 and 1965), it was concluded it could withstand construction blasting from below, as long as related vibration reaching the rock mass was restricted to the smallest technically possible fraction of the previously observed ambient natural vibrations.

Construction Blasting and Progressive Natural Changes in the Rock Mass

Ten years later in 1985–1986, following a lengthy process of decision-making, a two-lane parkway section of I-93 was constructed through Franconia Notch and beneath the Profile. The author (then a consultant) was retained by

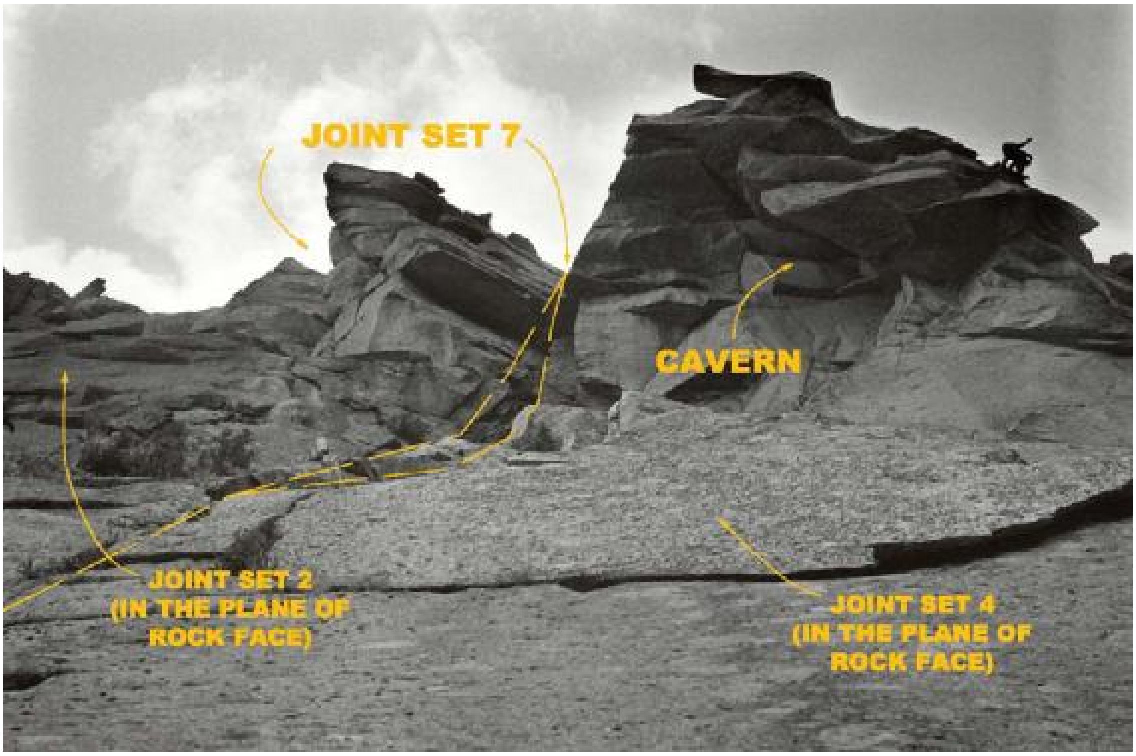

Figure 6. Profile's rock mass on the right (north) and adjacent rock mass on the left (south) showing location and influence of the two parallel Set 7 structures on block breakage patterns on the cliff (photo by S. Young, 1958).

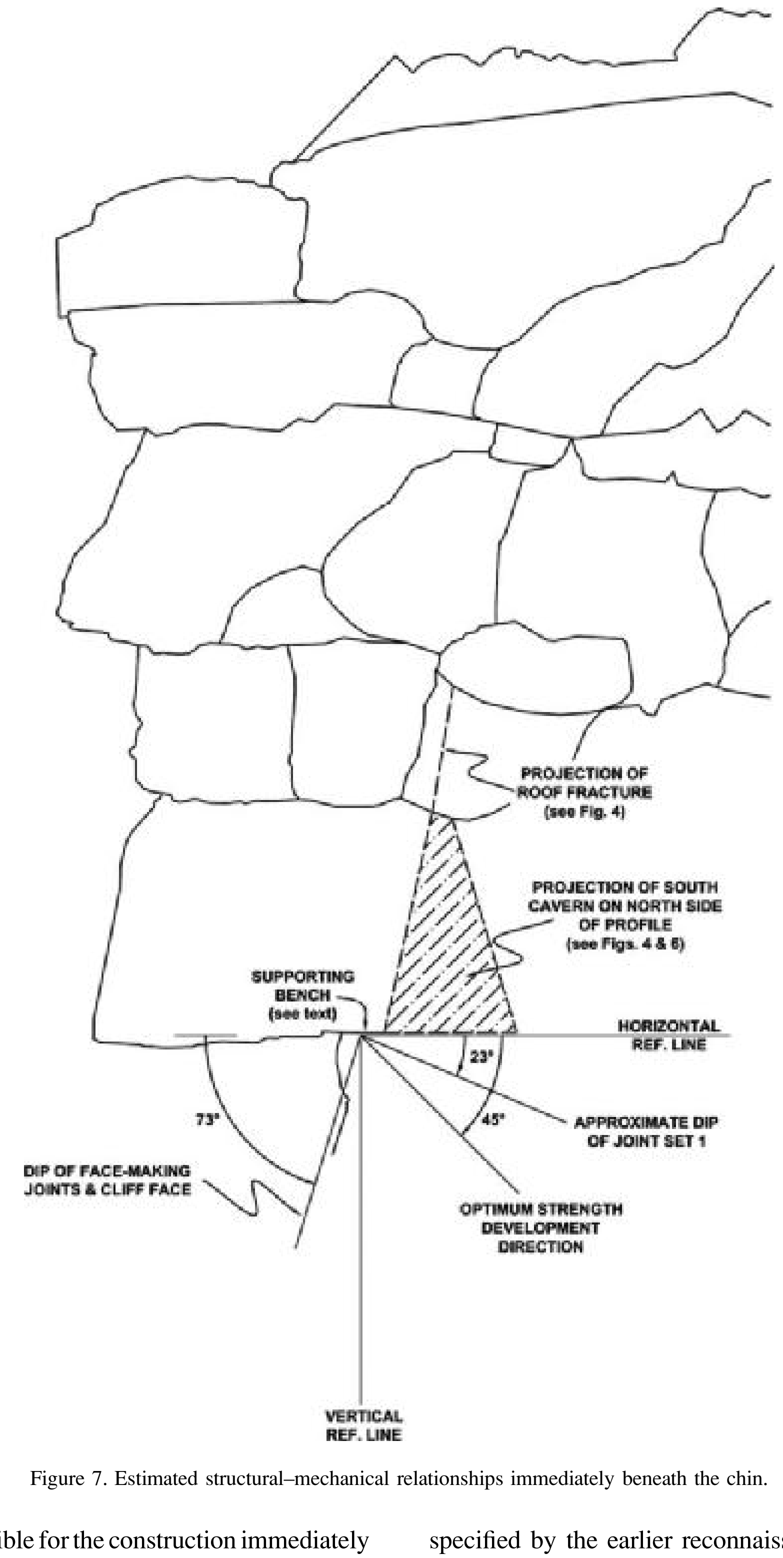

Figure 7. Estimated structural–mechanical relationships immediately beneath the chin.

the contractor responsible for the construction immediately beneath the Profile, to review the design of each blast before detonation to ensure minimal blasting-related vibration reached the Profile or its immediate vicinity, as specified by the earlier reconnaissance and the NHDOT contract. The work included field installation and maintenance of a sensitive, continuously recording seismograph on the cliff just beneath and between the Profile's rock mass and the blasting below. The purpose of this installation was to record all types of vibration that reached the rock mass during the entire construction period and to determine if this specification was continually met.

During the monitoring, each of the blasts detonated was detected by the sensitive instrument. Each detection recorded was just above the detection limit of the instrument (0.25 cm/second; 0.10 in./second). This demonstrated that no blast created a vibration at or near the Profile that was observed to cause damage or that approached 5% of the ambient natural vibration the Profile was otherwise enduring during the construction period (see below). In addition, and because blasting on earlier projects located further away and to the south of the Profile had been designed to meet the same requirement, the monitoring showed that none of the blasting along the corridor could have created potentially damaging vibration at or near the Profile's rock mass.

The continuous monitoring did detect other types of ambient natural vibrations with readings ranging from 7.1 to 13 cm/second (2.8–5.0 in./second), more than an order of magnitude greater than any related to the construction. The distinctive signatures of these non-construction vibrations were easily identified on the dated and timed records by their non-blast-time occurrence and their substantial difference in intensity and frequency from vibrations typical of blasting. Back checking and observations during instrument maintenance confirmed, as previously observed (Table 2: 1965), that these substantial vibrations resulted from wind gusts, thunderstorms, and aircraft over-flights. These observations showed that the Profile was simultaneously subjected to natural dynamic stresses significantly larger and more potentially damaging than those related to the construction.

Also during the maintenance visits, many incipient changes in the condition of the surfaces and fractures in the rock mass near the base of the chin were noted by comparing photographs with those from the earlier reconnaissance. These observations showed natural kaolinization decomposition was steadily deteriorating the granite and vigorous freeze–thaw cycling was quarrying off small blocks from nearby parts of the cliff. Speculation centered then and since (Fowler, 1997; Davis and Fowler, 1998) on how long these natural processes could continue before the Profile's stability was compromised. It was simply noted that these processes were those that formed the Profile, that they were for the most part uncontrollable by any then-feasible means on the lower portions of the rock mass, and that they would thus continue into the indefinite future with a generally detrimental impact on the security of the Profile.

Mechanics of Collapse

Eighteen years later, the Profile collapsed on May 3, 2003. Analysis of the mechanism and cause began immediately by careful comparison of photographs. The best of these comparisons are presented in Figure 8. These views, before and after collapse, respectively, permit fairly precise determination of what portions of the rock mass collapsed. The blocks marked A through D in both photographs show clearly that the chin and upper lip block combination fell away from the joints separating them from blocks A and B, and the failure line on Figure 8 shows the approximate back line of the blocks and portions of the rest of the blocks that collapsed. All portions of the original composite rock mass collapsed except for the rear portion of the forehead slab.

Figure 9 is a view of the top of the residual rock mass showing the un-collapsed rear portion of the forehead slab, into which the large stapled turnbuckles had been installed (Table 2: 1958) along with the residual rock mass below. The backward-curled pattern of deformation of the forward staples that were stripped out of the front portion of the forehead as it moved away indicates the rock mass toppled forward rather than sliding downward. Had sliding occurred, these staples would have been curled in the opposite direction and the line of breakage behind the Profile would not have been left as cleanly defined.

The toppling failure mechanism is also documented by the significant accumulations of weathered granite grus visible on the residual ledges below the residual forehead slab. These volumes of grus, formed by kaolinization weathering of the granite between joint surfaces within the rock mass before its collapse, are surprising given the extensive surficial efforts over the years to prevent such weathering by rain, meltwater, and wind-driven cloud water (Table 2: 1958). Had a sliding failure occurred, these loosely granular accumulations of grus would have been swept away with the collapse.

The mechanism and sequence of the collapse can be reliably conceptualized by referring back to Figure 7, a sketch of the Profile's pre-collapse rock mass viewed from the north. Based on all that was known of its pre-collapse structure and the particular stability of its various parts, it appears the collapse likely occurred in two nearly simultaneous stages.

As described earlier, much of the roughly triangular chin and upper lip block combination overhung the cliff below and was held in position by the weight of the three blocks above cantilevering the rearward triangular point of their combined mass onto the cliff at a point of bearing in the narrow granite bench below, located just in front of the cavern (Figure 7). Based on the surficial deterioration observations of 1985–1986, the extent of internal deterioration revealed by the collapse, and the fact that only incipient construction-related vibration reached the rock mass during I-93 construction, it appears that the naturally progressive processes of kaolinization decomposition and vigorous freeze–thaw degradation reduced the intact

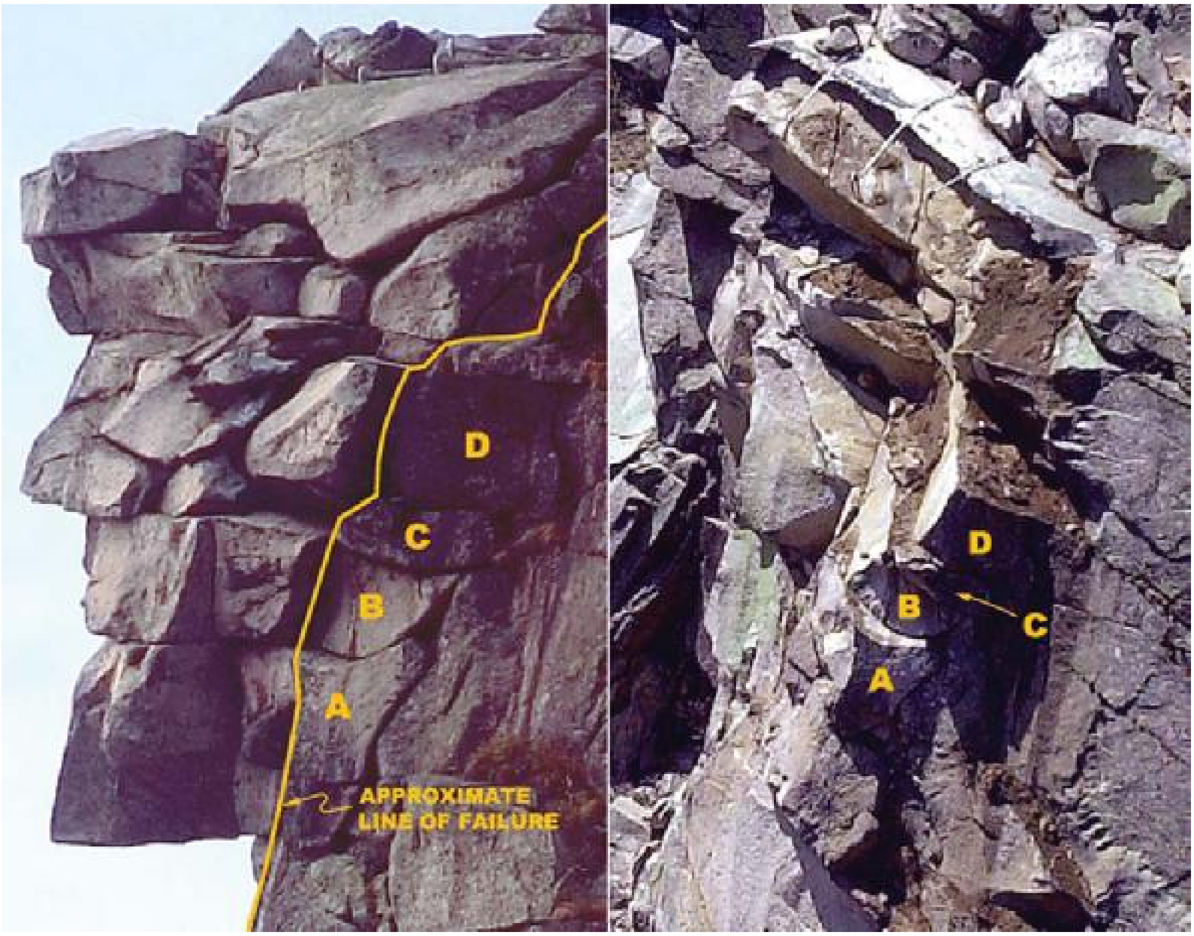

Figure 8. Profile's rock mass before and after collapse, showing extent of toppling failure. Note forehead turnbuckles in both views (photo at left by J. Cole, Associated Press, 2001; photo at right by Union Leader Corp., 2003).

strength of the granite in the narrow bench and gradually weakened it sufficiently so it could no longer remain intact. When this foundation suddenly disintegrated, the chin was no longer supported and toppled forward and downward, taking the upper lip and the rest of the rock mass above with it as the blocks broke off along the joints bounding them to the rear (Figure 7, fracture extension).

CONCLUSIONS

In the wake of the Profile's collapse, it is evident that the results of the rudimentary stability analysis of the mid-1970s turned out to be essentially correct. Its suggestions that the Profile's mechanism and circumstances of stability were delicate, that the chin and upper lip held the key to its security, and that it might collapse in a toppling failure all proved true. This validated most of the assumptions, methods, and heuristics that had to be used to complete the minimally funded work.

It is clear from the foregoing that the cause of the Profile's collapse was exclusively natural, there being no evidence of any kind of human-induced deterioration of its stability on the cliffside or of human influence in the initiation of the collapse. In fact, the collapse makes clear that many of the well-intentioned preservative activities intended to prevent water entry into the rock mass and to thus minimize weathering-based deterioration were largely ineffective. The collapse, while unfortunate for us in our time, is a normal consequence of the relentlessly penetrative mass-wasting processes that have been operating on the cliff since the departure of the last glacial ice from the Notch about 12,000 years ago (Thompson et al., 1999). In short, the natural processes that formed the Profile are the same as those that destroyed it.

Finally, the work of the last 28 years demonstrates that sometimes poorly funded, and thus rudimentary, studies like these can yield important results that should not necessarily be discounted for their relative lack of rigor or

Figure 9. Close-up, top of the Profile's residual rock mass (photo by Union Leader Corp., 2003).

sophistication of method. As the collapse of the Profile shows, those who were concerned that its constitution might not be able to survive attempts to save it were right. However, even if it could not be saved, at least these rudimentary studies accurately documented how the remarkably human feature formed, how it endured, and how it finally expired, coming together now as a compelling example of geology in action.

ACKNOWLEDGMENTS

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