Report on the Field Trip of a Lifetime

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Annually since 1992, Professor **Paul G. Marinos** of the National Technical University of Athens (NTUA) has led an internationally famous, 12-day, four-country field trip in the Alps (Figure 1) for over 200 third-year Civil Engineering students. Prof. Marinos and the NTUA also welcomes up to four Visiting Guests, many from Europe. However, there have been several visitors from North America, including Professors **Allen Hatheway**, **Abdul Shakoor**, **Paul Santi**, Irwin Novak, Mark Diederichs and Jean Hutchinson.

In March, 2010, I was a visiting guest on this field trip of a lifetime. This article is my brief report, in recognition that my airfare was paid as a Research Grant by the AEG Foundation. All of my other expenses were generously covered by NTUA and Prof. Marinos.

The intent of the field trip is suggested by the name *Engineering Geology in Engineering Works in Greece-Italy-France-Switzerland with Emphasis on Case Histories of Great Failures*. The field trip develops student awareness of the importance of Engineering Geology to the field of Civil Engineering by exposing them to engineering successes and, most importantly, to famous failures caused by unrecognized or neglected "geological details." About 25 locales of geology/engineering significance were visited and/or discussed, with special attention to the Malpasset Dam and Vaiont Dam failures. The faculty members assisting Prof. Marinos were Prof. George Tsiambaos, Sofoklis Maronikolakis and Dr. Vassilis P. Marinos.

We traveled on five buses, with a medical doctor, tour directors and patient bus drivers. We enjoyed good hotels and meals, and several fun (and educational) diversions. A chunky volume of Course Notes provided additional background to lectures (and this article). Special attention was also paid to cultural and historical aspects of the countryside visited. Students were organized into teams and were tasked with a report to prepare over the Easter break and group presentations to develop. Much of the approximately $1,100 per student cost was covered by NTUA.

Day 1

At dawn on March 20, there was hurried activity in the parking lot outside the Civil Engineering buildings as about 230 students gathered—shepherded by Prof. Marinos, the faculty and the Student Organizers selected by democratic votes of their peers. Over the next 12 days, the Student Organizers managed ticket and room distributions, banged doors for wake-ups, coaxed bus-loadings, and, settled squabbles.

We traveled to the port city of Patras to board the ferry for the 20-hour voyage to Ancona, Italy. Along the way to Patras we heard drive-by accounts of highway and railway connections between Athens and Patras, the active fault of Kakia Skala, the

The 2010 NTUA Field Trip Group at Vaiont Dam

Vaiont Dam

Gulf of Corinth and its seismic activity, the large Panagopoula Landslide, and the geological and engineering story behind the spectacular Rio-Antirion cable-stayed bridge crossing over the Gulf of Corinth near Patras. We made a site visit to the 4-km-long Platanos tunnel segment for the new high-speed rail connection between Athens and Patras. The lecture included an in-tunnel exercise to estimate the 10 cm of fault displacement in the 4.5 m diameter tunnel for predicted seismic events in the area, and discussion of design mitigations.

Day 2

As we approached Ancona, we listened to a deck-top lecture about Ancona's major landslides in Pliocene heavily over-consolidated marine clay. Landslides have disrupted the city since ancient times, most spectacularly in 1982 when 180 million cubic meters of ground moved, severely damaging the city, port, highway and railways. A key factor contributing to slope instability is a centuries-old history of clay quarrying at pits along the coast and excavations for building developments in the narrow strip of level littoral land.

We bussed to Venice. Enjoying a large boat all to ourselves, we visited St. Marks Square. Prof. Marinos stood on a table and presented a dramatic lecture in the misty dusk, telling of the subsidence of Venice, the 1902 collapse of the original Campanile in St Mark's Square, its rebuild in 1912 on wooden pile foundation, the subsequent subsidence due to piling deterioration and tilting of the structure, the ongoing remediation by ground improvement and foundation stabilization, and the grand schemes to protect subsiding Venice from flooding. We stayed at nearby Mestre for two nights and visited Venice both evenings to explore.

Day 3

We travelled about 100 km northwest of Venice into the Dolomite Alps to the Vaiont (Vajont) Dam, which occupies a narrow, high gorge cut into the core of a syncline. Access was limited and we had to walk in very long line beside the narrow road to overlook the dam (Figure 4). Most of the lecture was presented at a vista point on landslide debris upstream of the dam (Figure 5 and Figure 6).

Built in 1960, at about 267m high, Vaiont Dam was the world's highest thin arch concrete dam. A rockslide initiated in limestone on the left bank during filling, but slide creep movements were constrained by controlled fillings and drawdowns. Later investigations revealed that the shear failures occurred along 5-cm to 15-cm-thick seams of clay within the limestone rock mass. Pore pressure increases due to the controlled lake fillings and drawdowns had fatally weakened the clay seams.

At approximately 10:35 p.m. on October 9, 1963, more than 270 million cubic meters of rock slid at more than 60 mph from Mount Toc into the reservoir behind Vaiont Dam, filling the gorge with more than 400 m thickness of debris (seen in the photo at left). The width of the slide was 1.7 km and the maximum thickness of the slide more than 250m. The horizontal displacement was 250m. Thus a creeping slope ended in a rapid brittle-like failure. Loss of deep interlocking of the limestone rock mass and heat associated with the frictional movement of deep seated slide surface were also contributing factors.

A wave over-topped the dam by 245-meters, but barely damaged it. The flood raced 3 km down the Vaiont gorge into the Piave River Valley, where at 70-m-high it inundated Longarone and other Piave villages. About 2,500 people died.

The failure is one of the worst in the history of civil engineering, being a result of the failure of geologists and engineers to fully characterize site conditions, or to pay adequate attention to the evidence of slide movements and other warnings during the filling of the reservoir.

Tail end of the student line at Vaiont Dam

Lecture at Vaiont Dam

Pisa's famous "leaning tower"

Day 4

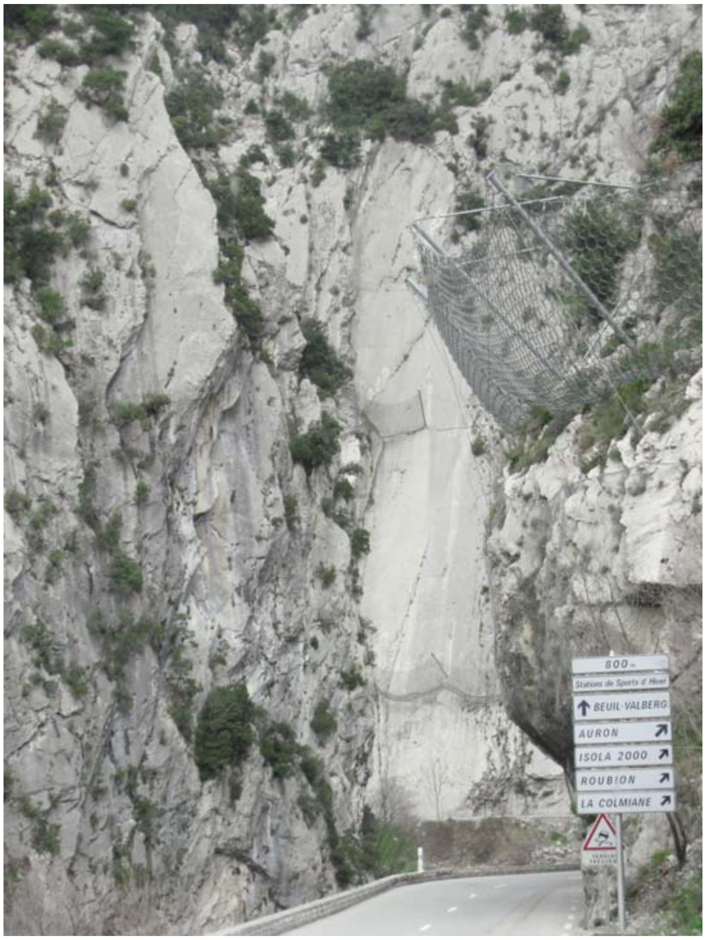
We left Venice for Florence. En route, we visited Verona, where I walked purposefully in the opposite direction to most tourists and thus missed seeing Juliet's house (Juliet of Romeo and Juliet), which is the prime tourist focus. At Florence, we enjoyed a few more hours of hurried tourist exploration. The technical focus was the catastrophic flooding of the Arno River in 1966, where up to 6 m of flooding occurred in the historical center and severely damaged Florence's artistic heritage. The flooding was due to heavy rain, deforestation of catchment areas due to wild fires, and aggravated by poor engineering and public policy decisions. From Florence we drove in the dark on roller-coaster-like, tortuously winding Tuscany roads, to Casino di Terra, near Cecina.

Day 5

The day started with us reluctantly leaving our pleasant, slow-paced Tuscan hotel. (How slow? How about only a telephone modem connection in the lobby?) En route to Nice, we visited Pisa where the focus was the famous Leaning Tower, which is actually the campanile for the nearby handsome Duomo (domed cathedral). The Tower was built between 1123 and 1370, with two long interruptions, during which the structure was already tilting and masons tried to make compensatory adjustments. The Tower is underlain by about 10 m of young and variable shallow water silts deposits, about 40 m of very soft and sensitive marine clays, and, dense sand to great depths. The watertable is 1 m to 2 m below the ground surface. Geotechnical exploration revealed that the surface of the clay layer is a dish-shaped depression.

The two long interruptions in construction were beneficial, allowing time-dependent strengthening of the clay. The building had fortuitously stopped both times at just the points that foundations soils would have failed with further loadings. Remediation attempted in 1938 worsened the tilt. Meanwhile, groundwater exploitation was forbidden as the resulting drop in groundwater-induced pore pressures dramatically affected the trend of tilting. By 1990, the inclination was 5.5 degrees from vertical, the top overhung the base by 4.5 m and the Tower was approaching its limit of leaning stability, due mainly, as recently revealed, to structural causes from the increased compressional stresses on its second storey. Various attempts in the past to stabilize the Tower seem mostly to have aggravated the tilt. There were heated debates about the applicability of stabilization schemes such as dewatering wells, electro-osmotic ground improvement and ground anchors. Stabilization has now been achieved by gently extracting soil from inclined boreholes, assisted by carefully adjusted lead weights, coupled with temporary cable supports during remediation. The fully instrumented stabilization procedure is a good example of the Geotechnical Observational Approach, where remediation and decisions are informed by a rapid and decisively interpreted data stream. Safe for at least another 300 years, the still-Leaning Tower was reopened for Public use in 2001.

The Leaning Tower in the background made for a fascinating out-door lecture and great snapshots—"Look at me holding up the Tower of Pisa!" We got to Nice late, but not too late for splendid dinner in a small restaurant which closed for the evening in order to serve us all in two sittings.



The road to Valle du Tinée

Day 6

We drove into the Southern French Alps along the beautiful winding Valle du Tinée. The road winds through narrow, steep and deep gorges surrounded by spectacular scenery. The road is a war zone, a struggle between nature and highway engineers. The engineers win a few battles with ever more tunnels, rock slope protections, rockfall restraints and route adjustments.

Our destination was La Clapière Landslide, one of the largest active landslides in Europe, which hangs over the village of St. Etienne de Tinée . The rockslide is about 750 m high and 1.1 km wide, largely within prominently foliated migmatitic gneiss. Measurements of slide displacements of up to 15 m annually have been made. On the basis of those measurements, in 1986 it was predicted that the slide would fail catastrophically around 1989, likely damming the Tinée River and causing consequent flooding of St. Etienne de Tinée. As a result, a contingency diversion tunnel for the river was constructed and the access road at the foot of the slide re-routed. Although the slide is still progressively failing, pro-active foresight has mitigated the effects of the eventual failure.

After a touching presentation in the Community Hall by the Mayor of St. Etienne de Tinée, we returned to Nice. En route we observed magnificent rock restraint systems beside the highways. We also took a break in Monte Carlo in the little Principality of Monaco, with its king-size, multi-story, extremely expensive Parking Garage. I could not help wonder how much engineering geology and geotechnical engineering must have been performed to develop the ultra-posh houses and apartment buildings that cascade down the steep slopes. Many students excitedly enjoyed their first visit to the Casino of Monte Carlo.

Day 7

We visited Malpasset Dam, on the Reyran River, near Fréjus in southern France. (Malpasset translates as "passes badly" or "doesn't go very well"—an appropriate name for the ill-fated dam, but actually the original hamlet was named for a highwayman who robbed passing stage coaches.) The day started in rain. As we walked the 2–3 km to the dam, we observed huge blocks of concrete in the steam bed. Many students were unaccustomed to the hiking and fording of the shallow stream. Prof. Marinos instructed on the use of the Geological Strength Index, and encouraged them to make geological observations under their umbrellas (below). Eventually, the sun came out and we had a splendid day of geology and engineering.

Completed in December 1956, the 67-m-high, 400-m-long, double-curved arch Malpasset dam was an engineering achievement, being the thinnest arch dam in the world. It took three years to fill the reservoir because of pending expropriation of lands in the reservoir area. During heavy rains of November 1959, the water level was still 7 meters below the top when small leaks were observed to have increased rapidly in the right abutment. Despite these signs of serious danger the local populace was not notified. There was heavy rain of nearly 50 cm of rainfall from 19th of November to the 2nd of December, with 13 cm in the last 24 hours. The reservoir level rose about 5m in four days. Permission to open relief valves was initially refused to prevent damage to a recently constructed highway bridge downstream. Minor overflow relief was finally allowed. But too late—at 10:35 p.m. on December 2, the dam tore apart. The cause was hydraulic uplifting of a massive wedge of rock under the dam, as the following briefly explains.

Geological characterization of the rock mass below the dam foundation and abutments had revealed a gneiss with a foliated fabric that dipped steeply toward both into the valley and downstream (thus with an unfavorable attitude at the at the left abutment) Shallow rock grouting and drainage of the dam/rock interface was performed, as conventional for the time. However,

ABOVE: Relic of failed Malpasset Dam

there was also unsuspected shearing in the foliated gneiss, as well as a cross-valley, steeply dipping fault that outcropped below overburden downstream of the dam. The shears and the fault bounded a massive rock wedge stressed by hydrostatic and uplift pressures.

With the relatively sudden increase in reservoir filling, the wedge was subjected to rapid incremental hydraulic pressure. It abruptly moved about 0.8 m along the weak fault infilling, leading to immediate progressive demolition of a major portion of the dam. A 40-m-high wall of water was released as a wave that flashed down the valley at 70 km an hour, killed at least 421 people in downstream Malpasset, Bozon and Fréjus, and destroyed railways, roads, farms and industrial buildings. The Malpasset Dam failure was the worst natural disaster of the 20th Century in France.

Following this catastrophe, the practice low of draining low-permeability foundations, in gravity dams was extended to arch dams as well. There were also major advances in the understanding of rock fracture hydraulics and the relationships between stress, permeability and degree of rock mass discontinuity.

One of the most memorable sights of the field trip was the vista of 230 students scattered over the sun-drenched torn rock of the left abutment of the dam, listening to Prof. Marinos lecturing through a bullhorn about the Malpasset dam failure. Visiting the site yielded a sobering lesson. For the students it became clear that whichever field of Civil Engineering that they chose to specialize in, Engineering Geology has a role, and the result of overlooking even small details of geology can be fatal.

From Malpasset we travelled to Aix-en-Province and then on to Gap.

Day 8

We got off to a slow start—some of the students had partied until dawn the night before, which was about the time the wake-up calls started ringing. So the Student Organizers had their work cut out for them rounding up the sleepy and sometimes party-challenged heads. It rained much of the day and was cold, especially for the students grouped on top of the 400-foot high Le Sautet Dam on the River Drac, near Corps, in the Isère Region of French Haut-Alpes. Le Sautet is a spectacular concrete gravity-arch dam that plugs a deep gorge in limestone (Figure 14). The dam was well built and the surrounding rock mass grouted to form a relatively impermeable barrier to leaks. Unfortunately, upstream of the dam, the reservoir has direct hydraulic access to an old and deeply buried river valley, an ancestral Drac River. The reservoir thus leaked much more than expected. Adjacent to the dam is a spectacular 75-m-high bridge, often used for bungee jumping (saut en élastique), but regrettably not a required activity on this field trip.

We stopped for a rainy wander and lunch in Grenoble, a town well known to Prof. Marinos since he earned his PhD there.

Le Sautet Dam on the River Drac

Day 9

Our hotel in Geneva, Switzerland, was a luxurious base to enjoy a Sunday off for exploration of Geneva. However, I travelled to Zurich to catch up on progress at the world-class SMDK project at Kölliken, where a hazardous waste landfill is being completely removed within a partially vacuum-controlled, enclosed structure.

Day 10

We left Geneva, for Milan, Italy—a long trip. In the middle of the day we spent about four hours at Chamonix-Mt. Blanc, in the French Alps. Most of us took a cable car trip to the top of Aiguelle du Midi, a tall horned mountain next to Mt. Blanc. The top is about 3,840 m—over 10,000 feet above the town. It was windy and cold, but the beauty (and altitude) was breathtaking. From the viewpoint we could see abundant examples of glaciations and avalanches. Later, heading toward Milan through the Mont Blanc Tunnel, we learned about the tragic 1999 Fire. We then sped down the Aosta Valley, with its spectacular rock falls, to our hotel on the outskirts of Milan.

Days 11 and 12

We travelled 500 km to Ancona, then back to Athens via the Ancona-Patras ferry to complete the 5500+ km Field Trip. On the ferry there was a last lecture—a "thank you" gathering of the students recognizing Prof. Marinos and the faculty in their leadership of this extraordinary field trip. I too was kindly honored.

There is nothing in the United States remotely like this university field trip. Students saw sights that most geotechnical/geological engineers only read about: the Vaiont Landslide, the Malpasset Dam failure, La Clapière Landslide, Venice subsidence and the Leaning Tower of Pisa. As extras, we enjoyed beautiful scenery, and, saw abundant examples of the interplay between challenging geology and the needs of man at cities, highways, slopes, dams and tunnels. And, we enjoyed some of the historical and cultural delights of Venice, Verona, Florence, Pisa, Nice, Monaco/Monte Carlo, Geneva and Chamonix-Mt. Blanc.

I am still in awe of the energy, commitment and skill of Prof Marinos, the faculty, the tour directors and the bus drivers in guiding 230 energetic, vocal, and bright young people over 12 days of traveling. I was impressed by the bright, engaging, and often curious NTUA students, their good manners and behavior, and their respect and attention to Prof. Marinos, the faculty and myself. We had no mishaps; there were no embarrassing scenes, and we lost nobody. I saw no tears or tantrums. I did see sadness while we looked upon the enormity of the Vaiont and Malpasset failures. I enjoyed the young people sharing with me their worries as to which areas of Civil Engineering they should specialize, and what they should plan for the next steps of their lives. Happily, based on their experience of the field trip, many students decided that they would focus their remaining studies on Geotechnical Engineering and Engineering Geology. It is unfortunate that we have no similar trip, with its recruitment appeal, in North America.

For technical and cultural reasons I was very fortunate to be a Visiting Guest on this trek. But I do not claim all the good fortune—Paul Marinos would be happy to host more Guests on future trips!

Acknowledgements

I am thankful to the AEG Foundation for providing me with a grant to cover my airfare to Europe. I have a particular gratitude to Prof. Marinos in that I was able to finally accept his oft-extended invitation to me to join the field trip. I appreciate his very generous financial support and his effort to make me, the Visiting Guest, a working part of his faculty team. Further, I thank Prof. Marinos for his review of this abbreviated summary of his field trip and for his many suggestions—which have improved the article. Thanks to the NTUA students and faculty for making me feel welcome. And finally, special thanks (again) to my wife, Julie, for putting up with yet another of my long absences from home.

Notes and References

This article is based on my field trip travel post at edmedley.com (search on "N.T.U.A, N.T.U.A"). Additional detailed information about Prof. Marinos' rationale and description of the field trip, as well as illustrative graphics on several of the failures, is provided in his article at www.GeoEngineer.org (search for "Marinos Field Trip"). The principal references used for facts in my article are from this article and the many references provided in the field trip Course Notes:

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About the Author

Dr. Edmund Medley, PE, CEG, has more than 40 years of varied international experience in Geological Engineering, Geotechnical Engineering, mineral exploration prospecting, and failure investigation. He is an internationally known expert on the characterization of bimrocks, such as melanges, fault rocks and weathered rocks. He is professionally licensed as both an Engineer and a Geologist in the United States, United Kingdom and Canada. He has contributed to about 50 publications and presented over 230 lectures, some of them as the 2008 Richard H. Jahns Distinguished Lecturer in Engineering Geology (the Jahns Lecturer preceding Prof. Paul Marinos.)

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