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Geotechnical Challenges in Highway Engineering in Twenty First Century: Lessons from the Past Experiences and New Technologies

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GEOTECHNICAL CHALLENGES IN HIGHWAY ENGINEERING IN TWENTY FIRST CENTURY: LESSONS FROM THE PAST EXPERIENCES AND NEW TECHNOLOGIES

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ABSTRACT

The Transportation Authorities and Highway Engineers around the world are facing different types of challenges today than their counterparts in the nineteenth and twentieth centuries. These challenges include developing new highways and bridges as well as retrofitting of existing roads and bridges deteriorated due to aging or increased vehicle loading. Frequencies of deterioration of existing roads and imminent bridge failures forced many Highway Authorities to evaluate the existing roads and bridges and prioritize their retrofitting to comply with current specifications and future conditions.

The new challenges of today include, but not limited to: a) Construction over poor foundation materials such as organic soils, old landfills, expansive and collapsing soils and non-availability of alternative routes; b) Right-of-way restrictions including construction in urban areas and proximity of existing structures; c) Dealing with environmental concerns that were not considered critical in the past and complying with stricter environmental and safety regulations.; d) Utilization of certain native on-site materials (considered problematic such as shale) in back fills and embankments; e) Higher vehicle loading as well as increase in size and number of vehicles; f) Expectations of the road users for better driving conditions, safety improvements and riding quality.

These challenges can be overcome by applying innovative ideas and using modern technology during planning, design and construction stages of highway development.

This paper identifies some of the new challenges of today based on past history and presents various tools to meet these challenges. With better and faster methods of analysis, use of new construction materials (such as low density fill materials, geo-synthetics, geo-foam, tensors), utilization of new procedures (such as soil stabilization, reinforced earth, soil nailing) and implementation of effective planning, execution and quality control, these challenges can be overcome in an efficient and cost effective manner.

This paper also identifies various current geotechnical practices, which may be considered inadequate for modern-day highway design and construction, but have not been updated for decades.

In conclusion, recommendations for revisions to inadequate geotechnical practices are presented in this paper in order to provide safe and sound design and construction guidelines from geotechnical viewpoint.

INTRODUCTION

Transportation Authorities and Engineers have come a long way from the first Depressed Motorway in Detroit, Michigan, USA to Autobahn in Germany and Super Highways all around the world.

Fig. 1 Davison Highway, Detroit, Michigan – 1946

Figure 1 shows the Davison Highway in Detroit, Michigan, the first depressed highway built in the United States of America. Figure 2 shows a seven level urban highway interchange in California, USA.

Fig. 2 Seven-Level Super Highway Interchange, California, USA

In the Twentieth Century significant progress in roads and bridges design and construction was made throughout the world. In USA, millions of miles of roads and highways with numerous embankments, bridges, culverts and viaducts were built during the post “World War II” era. Today, many of these infrastructures are old, and are considered to be unsafe, irrespective of maintenance and upgrading efforts. This is because the design parameters have considerably changed, our knowledge base has increased, and the user expectations are higher than ever before.

Significant increase in mobility was achieved after the invention of automobiles. Construction of US Highways changed the history of Twentieth Century America. The US highway system, as a part of the Progressive Era, shaped the nation and marked unprecedented economic and social growth. Other European, Asian, and African Countries as well as Australia and New Zealand also developed their transportation systems significantly during the Twentieth Century.

This decade, as the beginning of Twenty First Century, is also marked with significant progress in the Transportation Industry. However, as in the past, minor to catastrophic failures of the roads and bridges around the world occurred due to natural disasters, extreme weather, and human error. Most of these failures can be attributed to the failure of the ground supporting the structures. Transportations authorities, structural and geotechnical engineers in the twenty first century, all over the world, are now challenged with the task of preventing similar failures by retrofitting existing structures and using innovative designs for new structures. Fortunately, advances in engineered materials and cutting edge technology are also available and are being developed throughout the transportation industry to help overcome these challenges.

LESSONS FROM THE PAST EXPERIENCE

There was a common belief that all foundation failures are related only to soft and unsuitable soils. In fact, there may be numerous factors contributing to failures of roads and bridges. Let us look at some recent cases of failures in highway and bridges in different parts of the world for different reasons:

Earthquake Damage

Due to lack of knowledge and understanding, many of the earlier bridges and roads were not designed to withstand ground movement and liquefaction resulting from seismic events. For example, maximum damage during earthquake is dependent on peak particle velocity and not on peak particle acceleration as was the old belief.

Fig 3 1464 ft Baihua Bridge/Viaduct, Dujiangyan-Wenchuan Highway, China - After 2008 Earthquake

As an example of damage due to earthquake, Figure 3 shows collapse of few sections of the 1464 feet long Baihua Bridge along Dujiangyan-Wenchuan Highway in China after the 2008 Wenchuan Earthquake,

Figure 4 Pan American Highway Bridge Abutment Damage in Moquegua, Peru After 2001 Earthquake

Figure 4 is another example of damage during seismic event showing the Pan American Highway Bridge Abutment Damage in Moquegua, Peru after 2011 Earthquake. The yellow arrow in the picture shows the start of the abutment.

Fig. 5 Highway Collapse near Santiago, Chile – After 2010 Earthquake

Figure 5 shows the collapse of an urban highway near Santiago, Chile after 2010 Earthquake. Multiple cars overturned near the damaged section of the road,.

Storm and Flood Damage

Lack of attention to proper flood protection and drainage systems in earlier designs contributed to many pavement failures during or after major storm events.

Fig. 6 North Carolina Coastal Highway 12 Overwash – 2006

Example shown above in Figure 6 is the North Carolina Coastal Highway over-wash during an storm event in 2006.

Fig. 7 Flooded Highway 97, Pinepass- Chetwynd – USA

Fig. 8 Highway 97, Pinepass- Chetwynd – USA Flood Damage

As a recent example of flood damage after severe storm event in 2011, Figure 7 shows the flooded Highway 97 from

Pinepass to Chetwynd and Figure 8 shows the damage of a section of the same highway.

In recent years, provision of higher elevations, improved levee system design, adequate number of culverts, roadside drainage ditches and open graded sub-base with synthetic drainage blankets are widely used for mitigation of storm and flood related damages.

Landslide Damage

Landslides and rock slides may be triggered by seismic events, slope saturation from storm events, combined with weakened shear zones along bedding planes parallel to the slope.

Fig. 9 Landslide Damage – Capitol Lake, Olympia after 2011 Nisqually Earthquake in Washington

The example presented in Figure 9 shows Landslide damage at Capitol Lake, Olympia during 2011 Nesqually Earthquake in Washington, while Figure 10 shows the Road Damage due to the same seismic event.

Fig. 10 Extensive road damage during 2011 Nisqually Earthquake in Washington

Fig. 11 Landslide Damage - Golden Bay, Nelson, New Zealand

As shown in Figure 11, severe landslide damage occurred at Golden Bay, Nelson, New Zealand.

Fig. 12 2006 Rock-Slide - Highway 140 near Yosemite, CA

An example of rock slide is shown in Figure 12 depicting 2006 Rock Slide on Highway 140 near Yosemite, California, USA.

Extensive geological and geotechnical surveying and post construction monitoring of high-risk slopes can be used to mitigate slope failures.

A geological assessment of the site area and an appropriate geotechnical investigation followed by slope stability analyses using modern techniques may give an early indication about the safety of the slope.

Sinkholes

Lack of geological/geotechnical characterization of a project site can lead to problems like sinkholes, especially in areas of Karst topography.

Figure 13 A Car fell into Ottawa Sinkhole in Canada – 2012

An interesting case of an unprotected sinkhole is presented above in Figure 13 showing a car fell into an Ottawa Sinkhole on Highway 174 in Canada in 2012.

Fig, 14 Giant Sinkhole Pierces Guatemala – 2010

Another interesting case of sinkhole is presented in Figure 14 showing an unusually large sinkhole in Guatemala spurred by tropical storm Agatha in 2010.

In some cases, leakage in large storm sewers can undermine road sub-grade to create a sinkhole. Proper ground improvement by engineered backfilling, grouting, flowable fill or dynamic compaction can eliminate the creation of a sinkhole.

Soft Soils, Organic Soils and Wetlands

Congested urban areas and lack of alternative routing can often challenge a transportation engineering team to design a road passing over wetlands or soft soils. Examples shown above are: m) Collapsed section of Interstate I-10 (Santa Monica Freeway) built over a drained wetland in a congested urban area in Los Angeles, California and n) A one mile long road under construction through wetland.

Fig.15 Collapsed Section of I-10 (Santa Monica Freeway) Los Angeles, California,   Built on drained wetland

Figure 15 above shows the collapsed section of Santa Monica Freeway (I-10) in Los Angeles, California and Figure 16 shows a one mile long road under construction in Mississippi.

Fig. 16 Mile long road under construction through wetland

In addition, collapsible or expansive soils and rocks (Shale) are often encountered along the proposed road alignment.
Once the presence and extent of the unsuitable materials has been identified, various techniques are available to improve the ground conditions or mitigate the effect of these problematic soils and rocks. Some of the techniques use geo-grid reinforced aggregate mattresses and light weight fill materials.

Extreme Weather Damage

Extreme hot and cold weather, freeze-thaw cycle, and the use of de-icing salts, can damage pavement and bridges if not properly designed to mitigate the weather related effects.

Fig. 17 Sergeant Aubrey Cosens Memorial Bridge - Highway 11 Lactford, Canada – damaged in extreme cold weather in 2003

An example of structural damage in extreme cold temperature shown in Figure 17 is the Failure of Sergeant Aubrey Cosens Memorial Bridge along Highway 11 in Lactford, Canada due to extreme cold weather in 2003.

Fig. 18 Damage due to extreme heat in a concrete pavement

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An example of the damage due to expansion of a concrete pavement, without reinforcement and expansion joints under extreme heat is shown in Figure 18.

For extreme heat or cold temperature, proper material selection and provision of expansion and contraction joints are important. Concrete pavement should be reinforced as needed. For design of pavements under frequent freeze-thaw cycles, extensive research is in progress. Extending open graded aggregate base to frost depth with proper side drains is often a viable solution to mitigate damage due to freeze-thaw cycles.

GEOTECHNICAL CHALLENGES

The following presents a preliminary checklist for evaluation of potential geological and geotechnical hazards that may impact transportation projects:

A. **Problematic Soils**: Presence of organic soils, uncontrolled fill, natural collapsible soils, expansive soils, acid sulfate soils and corrosive soils along the road alignment can create significant serviceability and durability problems. Aeolian deposits of silts and fine sands in arid regions such as Loess, some wind deposited beach sands and volcanic ash are some examples of collapsible soils. Some collapsing soils are product of weathering and internal leaching of parent rock creating meta-stable residual soils. These soils collapse under a critical load upon wetting. Some plastic clay with high liquid limit expands with increased water content and exert significant force against any restraint such as foundations and retaining walls. Corrosive soils have constituents which adversely affect the durability of concrete or steel.

Special investigation should be undertaken to identify the problem soils and special design and construction methods need to be employed to mitigate problems related to these soil deposits.

B. **Problematic Rocks**: Shale, weathered Limestone and very hard granite may create problems for design and construction of roads and bridges. Research is in progress for use of shale in road bed and embankments. Design methods are being developed for foundations on weathered soft rock such as limestone. Heavy rock cutting equipments are now available to deal with hard rocks.

C. **Coarse Alluvium with Boulders and Cobbles**: Excavation, drilling and piling in these materials are difficult. Special equipment and techniques are to be used to overcome the challenges encountered in these formations.

D. **Poor Sub-grade Drainage**: Importance of sub-grade drainage cannot be over emphasized. Many pavement damages and surface deterioration can be attributed to poor sub-grade drainage, especially over clay sub-grade or shallow rock. Use of open graded sub-base, drainage fabric draining to road side ditches minimizes the detrimental effect of stagnant water below pavement.

E. **Possibility of Sinkholes:** In addition to Karst topography areas, abandoned mine areas and where underground streams wash out fines, possibility of sinkhole is significant. Proper geotechnical investigation often detects such conditions which can then mitigated using available ground improvement techniques.

F. **Soil Slope Instability:** Possibility of slope failure or landslides should always be investigated thoroughly for a road project. Study of local geological maps, record search for landslides in similar formations, site reconnaissance by an experienced geologist, geotechnical investigation and stability analysis by a geotechnical engineer will significantly reduce the chances of unexpected slope failure. Various methods of slope protection and stabilization are available including retaining walls, sheet piles, metal nets, short piles, soil nailing, rock bolts etc. Sometimes, a suitable vegetation cover may be sufficient to protect a slope.

G. **Rock Slope Instability or Rock Fall:** Deep cuts in **w**eathered rock with steep slope may appear to be stable but subsequently may prove to be unstable. Presence of mud seams, weak planes along fractures and weathering action on cut face may induce rock fall. Periodic monitoring of slope conditions may warn against catastrophic failure. Metal mesh and geo-grid may be used to increase the safety of road users.

H. **Earthquake Epicenter and Active Faulting Zone**: A record search of seismic activities around the project area is essential prior to selecting a site for a bridge or the alignment for a highway project. To account for seismic shaking, acceleration response spectra may be developed for each new structure location, in accordance with Local Seismic Design Criteria. Foundations and retaining structures should be designed to withstand the anticipated earthquake forces.

Presently, bridges are generally designed to withstand some magnitude of earthquake loading depending on the local seismic potential. However, the characterization of soil under dynamic loading and liquefaction potential is not always given proper importance. An appropriate geotechnical investigation program can detect the liquefaction potential at an early stage and the ground can be modified or the route may be changed to avoid catastrophic failures. Use of Lead Rubber Bearing or LRB for base isolation may reduce the earthquake related damage to bridge structures.

Fine sand and silt under water table in loose state has high liquefaction potential. Pre-consolidation or other ground improvement techniques are available to mitigate liquefaction potential.

I. **Unstable Pavement Subgrade**: Some cohesive soils at high water content are difficult to compact and remains unstable. Lime-stabilization, Cement-stabilization or Fly-Ash stabilization techniques can be utilized to improve such soils.

J. **Bridge Foundation Problems**: Soft soils, heavy loads and accessibility of foundation location are some common problems for bridge foundations. Deep scour potential for piers in flowing streams is often overlooked. Protecting bridge piers in navigable rivers is very important. Floating ice is also a danger not always accounted for.

Differential settlement of approach embankment and slabs relative to the bridge deck often create serviceability problems. Use of a transition slab can minimize the problem. Bridge abutments and wing walls are designed to withstand lateral earth pressure in addition to bridge deck load. Battered piles are often used to support abutment foundations. Reinforced earth with pre-fabricated facing is widely used for approach embankment.

K. **Erosion on Embankment Slopes or Stream Banks**: Slope surface protection needs to be taken into serious account in order to avoid recurring repair costs. In flat delta regions with meandering river flowing into bays, protection of stream banks (river-training) is an essential element in bridge design. There are instances where, after few years of flowing under the constricted channel under the bridge, the river meanders and finds its way around the bridge. Erosion control can be done with gabions, select graded boulders and cobbles, geo-grid and rock mat, concrete apron and other available technology.

L. **Earth Retaining Structure**: Starting with gravity walls and cantilever retaining walls, earth retaining structures entered the modern era with sheet piles, reinforced earth, slurry walls, cofferdams, and soil nailing. With difficult soil conditions, stability of a retaining wall in overturning, sliding and bearing, present considerable challenge to the geotechnical engineer.

M. Inferior Grade Aggregate in Pavement: When suitable aggregate for pavement is not available in large scale and importing aggregate seems to be cost-prohibitive, engineers may have to allow inferior grade aggregate for pavement construction. In such cases, extensive testing of the material to evaluate the actual properties of the aggregate must be performed. The results should be analyzed to incorporate in the pavement design.

N. **Freeze-Thaw Effects**: Pavements deteriorate considerably every year in areas with several freeze thaw cycles in one winter, such as in Michigan. Extensive research is in progress for a solution to this recurring problem. Currently, use of open graded aggregate to the frost depth, with effective sub-base drainage connected with side ditches seems to be effective.

O. Natural Springs & Artesian Water: Many of the slope failures can be attributed to natural springs weakening the surrounding soils by slowly washing fines out of the soil bed. In many instances, artesian pressure is created by presence of impermeable layers confining water below the natural water table. Special techniques to deal with water will be needed in these cases.

P. **Culverts beneath High Fills**: When required, special design methods should be used for culverts beneath high fills. Failure of such culverts can lead to costly repair.

AVAILABLE AND EMERGING TECHNOLOGY

For a successful highway engineering project**,** full use of conventional technology as well as application of new emerging techniques must be considered. Some of the considerations are listed below:

1) **Subsoil investigation** - using different drilling and sampling techniques, has become common practice throughout the world. In-situ testing such as: a) Standard Penetration Test, b) Vane Shear Test, c) Cone Penetrometer Test, d) Pressuremeter Test and e) Dilatometer Test, are available for obtaining soil strength and compressibility parameters with more reliability and accuracy.

2) **Geologic and geotechnical site characterization**-can be enhanced by using Geophysical Exploration Techniques such as: a) Seismic Refraction Survey, b) Cross-Hole Siesmic Survey, and c) Ground Penetrating Radar d) Infra-red Survey.

3) **Tomography**: *Tomography* refers to imaging by sections or sectioning, through the use of any kind of penetrating wave. A device used in *tomography* is called a Tomograph. Siesmic Tomography is being used in large scale earth imaging as shown below.

4)

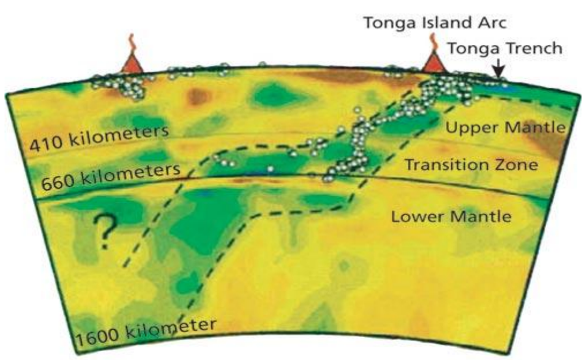

Fig.19 Tomograph Image of 410 km Tonga Island arc

4) Slope stability analysis and comparisons can be performed faster and with reliability using available computer softwares.

5) Geo-hydrologic modeling, using state-of-the-art computer soft-wares, has become easier and more dependable.

6) Soil structure interactions can be predicted using computer soft-wares.

7) New Tunneling Methods are being introduced from around the world. Recent developments include Earth Balance Tunneling, Micro-Tunneling, and New Austrian Tunneling Method using Rock Bolting and reinforced shotcrete.

8) **Soil-nail retaining walls** are being tested in some states with apparent success.

Fig. 20 Abutment Retaining System using Soil Nailing

9) **Seismic Analyses** has become easier with computer software. AnalysisNET is one of the comprehensive and advanced software for GeoSonics 3000 Series Seismograph.

10) **Design and construction of Soil Reinforcement** (Reinforced Earth) has become more reliable and field verified.

11) **Ground Improvement Techniques**: Excessive settlement potential of structures and pavements can be minimized by modern ground improvement techniques such as: a) Pre-consolidation with sand drains or wick drains, b) Vibroflotation, c) Blasting, d) Stone Columns, e) Dynamic Compaction, f) Compaction Grouting, g) Deep Soil Mixing.

12) **Total Stress Tensor/Kroneker delta:** Soil mechanics for unsaturated soil is gaining momentum with the use of total stress tensor and Kroneker delta.

INNOVATIVE MATERIALS

Following are a few of the innovative materials used in geotechnical applications:

1) **Geo-Textiles** or Geo-fabrics are usually made of petroleum products such as polyester, polyethylene, polypropylene or fiberglass. Geo-fabrics may be non-woven, woven or knitted. Geo-Fabrics have four primary uses: Drainage, Filtration, Separation, Soil-Reinforcement. Geo-membrane is mostly used for landfill covers.

Fig. 21 Geosynthetics in Road Construction on Soft Soil

2) **Geo-Grids** and Geo Cellsare high modulus polymer materials prepared by tensile drawing. Major function of Geo-Grids is soil or rock reinforcement.

3) **Wick Drains**: Prefabricated Vertical Drains (PVD), commonly known as Wick Drains, are used to accelerate pre-consolidation of thick soft strata to reduce settlement.

4) **Geo Foam:** Over 100 times lighter than soil, EPS Geo-foam continues to prove to be successful in high-volume fill and soil stabilization projects such as roads, bridges, levees and buildings. Many City and County agencies have used Geo-foam in many projects to simplify construction and reduce costs for public works projects.

Fig. 22 Geofoam used for US 50 near Montrose, Colorado

An example of the use of Geofoam is shown in Figure 22 showing Geo-foam used for US 50 near Montrose, Colorado.

According to the manufacturer of Geo-foam, has many features and benefits to help overcome common geotechnical challenges: high load-bearing capacities, does not decompose, decay, or produce undesirable gases or leachates, fully recyclable, durable and does not require maintenance under normal conditions throughout service life, unaffected by freeze-thaw cycles, moisture, and road salts.

However, there are still some issues related to its long term structural stability and environmental concerns. Typical road construction over soft soil is shown in Figure 23.

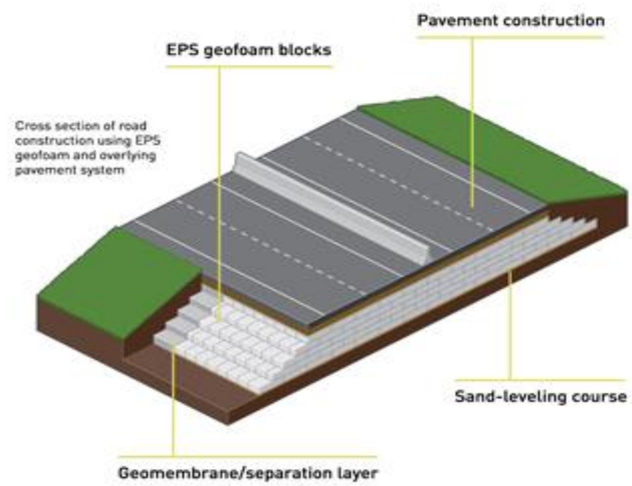

Fig. 23 Typical Road Construction over soft soil

5) **Metallic Soil Reinforcing Strip**: Metallic Strip Reinforcement is used with reinforced concrete skin to construct reinforced earth retaining walls. Fiberglass strips are also available for soil reinforcement.

FUTURE CHALLENGES FOR GEOTECHNICAL ENGINEERS

One of the major challenges for the old timer Geotechnical Engineers is to overcome any reluctance or hesitancy to use and trust electronic data collected onsite, using state of the art instruments and commercial computerized systems. The challenge is to decide what and when to trust and how to interpret electronic output with understanding the limitations of the system.

Tomography can generate an electronic three dimensional picture of what is under the surface of project sites, complementing, or in some cases replacing traditional methods of site investigation. In other words, subsurface exploration is taking a different approach than we have been accustomed to in the past.

One of the real challenges for the future geotechnical engineer is the transition from customary methods and techniques. Combining some of the traditionally used techniques with the new age ones, specially use of tensor techniques for unsaturated soils, will enable more confidence in final designs and construction of future projects.

Computer-based design techniques using electronic data have had a growing presence over the last 15 to 20 years. The challenge is to understand the capabilities and limitations of the computer programs and complete knowledge of how the program works, what input is required, and what output is generally expected. If simple checks on validity of input and output are not conducted, and the limitations are not recognized, the design answer may be incorrect and unsafe.

A probabilistic approach is increasingly incorporated in geotechnical design and analysis to account for the uncertainty and variability of Mother Nature. Factor of Safety approaches will give way to acceptable deformation approaches as quantitative expressions of uncertainty and variability can be incorporated into design considerations. Load and resistance factor design (LRFD) techniques for geotechnical components are being developed internationally and will be widely used in the near future.

Recently, due to economic downturn, Public agencies have experienced reduced in-house staffing for several years, although workloads have not changed, client expectations has increased while budget and time schedules have tightened. As a result, outsourcing of various components of public projects has and will continue to grow. The challenge here is to maintain the quality and integrity of the outsourced work from soil sample retrieval, to testing, to design, and finally, to construction.

Quality control of geotechnical work must not be outsourced, but assigned to experienced in-house staff. This means that an agency must still maintain an active in-house training program in all geotechnical aspects of the projects it is responsible for. There has to be a well developed quality control and quality assurance program for the agency engineers to use.

With shorter planning, design, and construction schedules, one has to really work to ensure proper and complete communications take place. There must be clear and concise communications between units within any specific organization, and between all organizations involved in a project.

Politics are an inevitable consequence of serving the public. So Engineers need to develop an understanding of the politics involved and learn to work within the political framework present to produce and maintain a quality transportation product for the public.

All of the advances in techniques, equipment, design, and construction methods, along with continuing research and development, the geotechnical engineer has the opportunity to provide the most accurate, detailed geotechnical designs than ever before.

Geotechnical engineers should not be afraid to use all the devices currently available, and they should not rest on the laurels of the past. There is still room for improvement, and this comes through research and the implementation and use of research results, motivated by the insistence by engineers for creative solutions to meet the professional challenges of today and tomorrow.

CONCLUSION

Performances of transportation infra-structures are generally monitored and failures are recorded and investigated. Lessons learned from the past must be compiled and shared so that the researchers and innovators around the world can focus their attention to real life problems and come up with new materials and design techniques. available to Road and bridge Engineers. Transportation authorities, planners, designers should understand that each highway project is unique and must be treated as such. A multi-discipline team, including geologists, hydrologists and geotechnical engineers must be involved from the early planning stages.

In the USA, many State Transportation authorities, such as, CalTran, MassDot, MDOT, have updated their Roads and Bridges specifications and have started or upgraded their Geotechnical Engineering Department to be involved in all aspects of Highway planning, design and implementation. Caltrans Earth is a source for planning, programming, operations, maintenance and asset information, all overlaid on high resolution imagery and terrain in a web based, 3-D virtual globe focused on California.

Many Universities are collaborating with the Transportation Authorities to conduct cutting edge research and field applications to advance the technology in various sectors. New and recycled materials are being tested for different use in the geotechnical and transportation industry. All these innovations are electronically available through research papers, symposiums and publications which are good sources for the Twenty-First Century Engineers.

REFERENCES

1) TRB Transportation Research Circular E-C116 – April, 2007 - Geotechnical Challenges of the Interstate Highway System.

2) Earthquake Engineering Research Institute - Firsthand reports and photos – May, 2008 Wenchuan Earthquake Info.

3) Pacific Earthquake Engineering Research Center, Berkeley. Geotechnical Report from June 23, 2001 Peruvian Earthquake.

4) Reuters/Marcos Fredes –February, 2010 -Earthquake in Chile – The Big Picture

5) ICF International – October 2008 - Long Range Strategic Issues Facing the Transportation Industry – Prepared for National Cooperative Highway Research Program Project 20-80, task 2.

6) Scott L. Douglass – 2011 - FHA Hydraulic Engineering – Highways in the Coastal Environment, Second Edition.

7) Flickr – Photo Sharing - 2012 - Highway 97 Flooding – Pine Pass to Chetwynd.

8) Wikipedia - 2001 Nisqually earthquake.

9) Institute of Hazard, Risk and Resilience Blog – January, 2012 - A photo album of landslide damage at Golden Bay, Nelson, New Zealand.

10) Peter Fimrite / San Francisco Chronicle, June, 2006 - Yosemite / Slide blocks road into park / Highway 140 buried.

11) National Geographic Daily News – June 2010 Sinkhole in Guatemala: 2010 sinkhole spurred by tropical storm Agatha.

12) Nigeria News, Ottawa, July 2012 - New Ottawa Sinkhole Report.

13) Rosa L. Santoni & Jeb S. tingle – Army Engineer Research & development Center, Mississippi. - Building Roads on Soft and Sandy Soils.

14) Road Construction – Geofoam.org.

15) World Highways – December 2008 - Advances in geo-synthetics boost soil stabilization.

16) Anoosh Shamsabadi – Office of Earthquake Engineering, Caltrans – January, 2009 - Geotechnical Modeling and Capacity Assessment.

17) John Berneich - May, 2009 - The Importance of Site Characterization on the Seismic Reevaluation of Existing Dams.

18) John Diehl, Geo Vision – January, 2010 - Borehole Geophysics for Geotechnical Engineering.

19) Woods Hole Oceanographic Institute – December 2012 - The Engine that Drives Earth - Tonga Island Arch –Seismic Tomography.

20) History of the US Highway System – www.gbcnet.com/ushighways/history