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GROUNDWATER CHANGES AND SOIL LIQUEFACTION INDUCED BY EARTHQUAKES

by

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ABSTRACT

There are two causes of raised pore pressures resulting from earthquakes, both of which may lead to geotechnical failures. The first of these, the consolidation of superficial deposits leading to loss of stiffness and ultimately liquefaction, has now been explored in detail and is relatively well understood. However, there is a second 'seismohydraulic' phenomenon that occurs when water expelled as a result of coseismic crustal strain emerges through some poorly-drained unconsolidated material. Such water release leading to rising excess pore pressures is particularly significant in normal fault earthquakes and some of the largest earth flow phenomena following these events can be shown to have been caused by seismohydraulic pore pressure increases. As this release of water from beneath the unconsolidated sediments may produce failures in materials that would not otherwise be affected by the earthquake, it constitutes an important and previously unrecognised geotechnical hazard.

INTRODUCTION

It is now generally accepted that liquefaction in a particulate material is associated with high pore pressures and low effective stresses. The loss of stiffness, and ultimately loss of strength that accompanies excess pore pressure rise in soils often causes permanent ground movements which have had dramatic consequences, especially when these occur within the urban environment. The source of these excess pore pressures was originally thought to be the soil itself, exhibiting a spontaneous collapse; the looser the soil the more likely the possibility of liquefaction. Certainly, loose saturated soils can provide substantial excess pore pressures but in consolidating, these soils will be exhibiting stable plastic yielding, far removed from the unstable flow-type movements which are observed in the field.

On the contrary, centrifuge model tests have shown clearly that it is the combination of low effective stress and a high hydraulic gradient which is critical to the occurrence of the phenomenon generally known as liquefaction. A loose consolidating sand layer ejects water, which in flushing upwards fractures the overlying deposits and provokes a buoyant debris flow. The fracturing of the soil by the creation of fissures dramatically alters its permeability. This breakdown of the continuum by tensile cracking has been one of the main reasons why the prediction of liquefaction has eluded numerical modellers for so long.

In design, it is still common to use SPT blowcount as a measure of the liquefaction potential of a site

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although it is clear that low values of blowcount merely indicate a zone which may form one source of pore fluid if consolidation of that soil were to be provoked either by earthquake shaking or for some other reason. Any subsequent liquefaction will occur because the settling velocity of the compacting deposit has reached the terminal velocity of particles or clumps of particles in the pore fluid. In the case of a level bed, clearly this velocity will be a maximum at the surface and hence the liquefaction front advances downwards, starting at the exterior (and not the interior) of the loose zone.

In general, the water-table (or phreatic surface) is below the ground surface. However, the phreatic surface flushes upwards and will often reach the surface, leading to the discharge of water from the ground. These conditions may persist for some time after the earthquake as it takes time for the excess pore pressures to dissipate and for the solidification front to advance upwards to reach the surface.

However, there is a class of phenomenon that liquefaction has never been able to explain: significant increases in groundwater flow that may sometimes continue for several months following earthquakes. These were once very widely reported, but in the 20th Century have often tended to be dismissed as part of some pre-scientific earthquake folklore. However, it has proved possible to find the geographical extent and magnitude of these hydrological changes. These have been shown to correspond in both extent and magnitude with crustal strain that accompanies fault rupture.

SEISMOHYDRAULIC PHENOMENA

Strain changes are well known from laboratory experiments to be accommodated in crustal rocks by the opening and closing of water-filled micro-cracks and fractures. The sign and geometry of the strain changes accompanying fault movements are dependent on the style of faulting (normal, reverse, strike-slip etc.). In a region of active extension, in the inter-seismic period the crust is stretched, opening cracks within the rock-mass and increasing crustal porosity. At the time of the fault rupture, the strain that was formerly distributed across a wide volume of the rock becomes transferred into fault displacement and the crust surrounding the fault undergoes compressional elastic rebound. In contrast, in a region of active compressional tectonics, the crust decreases in porosity between earthquakes and at the time of reverse fault displacement undergoes extensional elastic rebound.

In regions where there is no impermeable sedimentary cover above the crystalline basement, sudden changes in crustal porosity can be expected to communicate through to the surface. Compressional elastic rebound accompanying normal faulting will tend to raise crustal pore pressures and cause water to rise up fractures to feed surface springs. In contrast, extensional elastic rebound around reverse fault displacements will tend to draw water into the crust. This phenomenon, of changes in hydrogeology that accompany co-seismic strain, has been termed 'seismohydraulics'. There are two factors that can make this seismohydraulic release of groundwater cause critical increases in pore pressure: first its concentration and second its emergence from beneath the superficial deposits.

The water expelled at the surface does not cause a uniform regional rise in water-tables but emerges through individual springs that overlie the major arterial fractures through the upper crust. The impact of such flows on pore pressures of superficial deposits will be determined by the available natural drainage. If this water continues to flow into a porous sand or gravel that is overlain by a relatively impermeable clay horizon then inevitably that deposit will lose its strength and begin to flow. The chief way in which these phenomena can be distinguished from failure in response to vibration induced liquefaction is a result of timing. Liquefaction induced failures caused directly by consolidation of superficial deposits will occur during or for a short period after the end of ground shaking as the drainage paths for shallow deposits are short and the fissuring will have greatly increased the local permeability. In contrast, the rate at which seismohydraulic effects communicate with the surface is determined by upper crustal permeabilities. Typically, peak discharge occurs within 2-10 days of the earthquake. However, there is a distinct class of seismohydraulic phenomena that result from high levels of strain along the fault-plane itself and which is directly comparable to liquefaction of the superficial deposits. In these events, water is forced out at the surface under considerable artesian pressure within a few minutes of the earthquake, probably as a result of spontaneous hydro-fracture. Such effects are, however, only found in the hanging wall of a dipping fault within a few kilometres of its surface trace. Although the regional increase in groundwater flow is most pronounced in normal fault earthquakes, significant increases are also found accompanying strike-slip and reverse fault earthquakes although distributed in different regions around the fault and with lower magnitudes of discharge than are encountered in normal fault earthquakes. Even relatively small normal fault earthquakes have the potential to cause significant changes in groundwater flow and the level of the water-table.

ENGINEERING IMPLICATIONS

Where any major eruption of water occurs beneath overburden, it would be very likely to be mobilised into a flow-slide. The hazard will be particularly concentrated where there has been recent sedimentation or where the overburden has been dumped into its present position by man, as in the construction of a mine spoil tip, a road embankment or earthfill dam. Site investigations which relied on blowcount in superficial deposits would clearly be insufficient to comprehensively assess the likelihood of permanent ground movements at a site, particularly where landslides were concerned. Liquefaction induced flow-slides are only one manifestation of the problem, however. Any additional increase in pore pressure in the near-surface deposits will result in a degradation of shear stiffness and consequential permanent strain. Where this is not accounted for in the design of a structure, there could be serious consequences, for example, in the permanent movement of a bridge abutment or differential settlement of an industrial facility thought to be constructed on 'non-liquefiable' foundations. Remedial measures to achieve levels of drainage satisfactory to ensure the stability of major landslides or embankments may be not be sufficient where sub-slide spring-flows undergo major increases in discharge following a nearby fault movement. Increased pore-fluid pressures following an earthquake may also affect underground structures. A number of mines have been subject to increased water flows following an earthquake. Such problems could also affect road or rail tunnels in which the pumping capacity may be insufficient to cope with an unexpected increase in seismohydraulic groundwater flow. These phenomena are of particular significance to the siting of repositories for toxic and radioactive waste, in particular in saturated-zone crystalline rock. Seismohydraulic effects may have the potential to temporarily short-circuit the contaminated groundwater up to the surface as a result of increased pore pressures as fractures that were previously closed may become channels for fluid flow.

CONCLUSIONS

Hence, in defining the stability of a site, slope or embankment or in exploring the long-term hydrogeology of a subsurface tunnel or repository, it is necessary to explore not only the potential for liquefaction caused by consolidation of superficial deposits but also the potential for increased pore pressures resulting from sub-surface strain. Those locations subject to fluid expulsion following earthquakes may be characterised by the presence of certain forms of mineralisation (such as travertine) and craters or fissures. The locations most susceptible to such processes can also be predicted by strain models of faulting. This is a significant and previously unrecognised hazard that has implications for a wide range of site investigations in areas of active tectonics.

ANNONCEMENTS

Nomination for S.N.Gupta Memorial Lecture

Prof. Vijaykumar Gupta of Colorado University, Boulder (USA) has donated a sum of Rs. 2.5 lakhs towards hosting a memorial lecture in the field of Hydraulics and Hydrological Engineering in the name of his father, late Shri S.N.Gupta, former Secretary, CBIP and Director of U.P. Irrigation Research Institute, Roorkee. The lecture series was started from the year 2003. Nominations are invited for delivering the lecture in this series.

The nomination letter should contain information about his expertise of the topic on which he will speak. The lecture would be held during International Conference HYDRO 2015 at IIT, Roorkee. The last date for receiving nominations is 30th Sept, 2015.

Nomination for ISH R J Garde Life Time Achievement Award

The Indian Society for Hydraulics has instituted Life-Time Achievement Award for Hydraulic Engineer / Scientist from India who has contributed significantly in the field of hydraulic engineering and water resources. The award consists of Rs. 10,000/- and a citation. Nominations/proposals are invited from the ISH Life members for the year 2014-2015. Self nominations are generally discouraged. The last date for receiving nominations is 30th Sept, 2015.

Nomination for Prof. R J Garde Young Researcher Award

ISH Constituted this Award in memory of Late Prof.R.J.Garde with the deposit offered by his family and his students to promote the young researchers in the field of Hydraulics and Hydrology. It shall be awarded in the form of a cash prize of Rs. 10000/-, a memento and a certificate. This year the award shall be presented during the International HYDRO Conference 2015 of the ISH to be held at IIT, Roorkee. The nominations should be submitted to the ISH Secretariat for further processing. The award shall be given to young engineers, scientists and researchers who have not completed 45 years of age. The award will be open to Indian Nationals only. The award shall be given mainly for the work done in India in the area of Water Resources Engineering in general and Hydraulic Engineering in particular. ONE complete nomination package should be submitted to the ISH in the form of soft copy as well as in a CD by 30th Sept, 2015. The following information must be included in the nomination.

1. Name of the Candidate with complete postal Address and mobile number, E-mail, date of birth, age, on last date of nomination
2. Letter of nomination including a statement of 500 words of the Significant Contributions and / or national/ international impact and future potential.
3. Two letters of recommendation
4. Chronology of education
5. Chronology of jobs held
6. Complete list of referred publications in journals and conferences (Not more than five (5) significant recent publications are to be attached)
7. Certificate of age should also be attached
8. Any other relevant information

Announcement for International Conference HYDRO 2015

Indian Institute of Technology (IIT), Roorkee, and Indian Society for Hydraulics (ISH) are jointly hosting 'International Conference HYDRO 2015" on Hydraulics, Water Resources, Coastal and Environmental Engineering, December 17- 19, 2015.

The "HYDRO 2015 International Conference" represents a link in the chain of such "Hydro" conference organised annually in India over a period of last two decades under the auspices of Indian Society for Hydraulics. The conference would provide a forum for presentation and exchange of knowledge and research experience gained in the field of hydraulics, water resources, coastal and environmental engineering by scientists, academicians, practicing engineers and consultants.

Extended versions of the selected papers presented in the conference may be published in ISH Journal of Hydraulic Engineering, Taylor & Francis, UK.

Following web pages provide more details of the conference.

e-mail : **zulfifce@iitr.ac.in / zulfifce@gmail.com**

web : **http://www.hydro-2015.com**

Nomination for Prof. U. C. Kothyari Best M Tech & Ph D thesis Award

ISH Constituted this Award from the year 2013 to encourage the young Indian students of recognized educational institutions in the area of Water Resources Engineering in general and Hydraulic Engineering in particular (Water Resources, Environment, Coastal Engineering). The Dissertation/Thesis must have been successfully defended during September 30, 2013 to August 31, 2014. The award will be in the form of a cash prize of Rs. 8,000/- for the M Tech dissertation and Rs. 10,000/- for the Ph D thesis and a certificate. This year the award shall be presented during the International HYDRO Conference 2015 of the ISH to be held at IIT, Roorkee. The nomination should be submitted through a recognized educational institution to the ISH Secretariat for further processing. The award shall be given to young engineering, scientific or research students of Indian nationals. The last date for receiving nomination is 30th Sept, 2015.

The nomination should be sent as an email attachment to the Secretary, ISH at the following Email address: **ish_office@rediffmail.com**

It should contain the following:

(i) A cover letter that should include one-paragraph CV of the candidate and supervisor,

(ii) pdf file of the dissertation/thesis not exceeding 10 MB in size,

(iii) Any other recognition received for the dissertation/ thesis, Journal papers published based on the work, transfer of technology, if happened,

(iv) Names and affiliations of the referees who acted as examiners,

(v) Copies of the examiners' reports, if possible – not mandatory.

ISH assures full confidentiality/copyright of the dissertation/thesis, which will be used only for the purpose of deciding the awards.

FORTHCOMING CONFERENCES / SEMINARS

Sr. No.	Name of Conference	Date	Venue and contact details
1	ICSWRM 2016 International Conference on Sustainable Water Resources Management	January 26 - 27, 2016	Jeddah Hilton Hotel North Corniche Road, Jeddah 21362, Saudi Arabia http://waset.org/conference/2016/01/jeddah/ICSWRM
2	EWRI, ASCE 8th International Perspective on Water Resources and The Environment	January 4-6, 2016	Colombo, Sri Lanka http://www.ipweconference.org
3.	(CMWR) 2016 Computational Methods in Water Resources	June 20-24, 2016	University of Toronto, Canada, cmwrconference.org
4	2016 AWRA Spring Specialty Conference: Water - Energy – Environment	April 25-27, 2016 AK 25th -27th April 2016	Sheraton Anchorage, Anchorage, http://www.awra.org/meetings/Anchorage2016/
5	2016 AWRA Summer Specialty Conference: GIS and Water Resources	July 11-13, 2016	Sacramento West Hotel, Sacramento, CA http://www.awra.org/meetings/Sacramento2016/
6	2016 NWRA Annual Conference Week Activities	Feb. 29 - Mar. 3, 2016	Las Vegas, Nevada http://www.nvwra.org/2016-annual-conference-week/
7	Sixth International Conference on Water Resources and Hydropower Development in Asia	March 1-3, 2016	Conference and Exhibition Vientiane, Lao PDR http://www.hydropower-dams.com/ASIA%202016.php?c_id=303
8	IWA 2016 Water Loss Conference 2016	Feb. 1-3, 2016	Hotel Lalit Bengaluru, Karnataka 560001, India www.waterloss2016.com
9	11th IWA SG Conference Wastewater Pond Technologies - University of Leeds, UK	March 21-23, 2016	sarahbrown@aquaenviro.co.uk
10	5th IWA/WEF Wastewater Treatment Modelling Seminar	April 2-6, 2016	Annecy, France WWTmod2016.irstea.fr
11	The international conference on Water Resources In Arid Areas: The Way Forward	March 13-16, 2016	Sultan Qaboos University in Muscat, Sultanate of Oman. https://conference.squ.edu.om/Default.aspx?tabid=2012
12	12th International Conference on Hydroinformatics	Aug 21 & 26, 2016	Incheon, South Korea http://www.hic2016.org/html/index.php

List of New ISH Life Members Joined from 1st January 2015 to 30th June 2015

LM No.	Name	LM No.	Name	LM No.	Name
1131	Dr Gupinath Bhandari	1138	Prof Vidya Saraf	1145	Mrs Nayana Ninad Chavan
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1133	Shri Abhijit Dilip	1140	Shri Manish Kumar Sinha	1147	Shri Harinarayan Tiwari
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1137	Shri Deshmukh Anandrao R.	1144	Shri Boppana Vishnu Sankar		

THE INDIAN SOCIETY FOR HYDRAULICS

(FIXED DEPOSIT AND SAVING BANK BALANCE STATEMENT AS ON 30.06.2015)

1	Canara Bank(S.B A/c No. 25801010000822)	₹ 145934
2	State Bank of India (S.B. A/c No. 30633921394)	₹ 86092
	Total in Saving Bank Accounts	**₹ 232026**

Sr. No.	Name of Bank	Date of Deposit	Date of Maturity	Amount ₹	Rate of Interest
1	Canara Bank,	23-May-12	23-May-15	150000	9.00%
	Khadakwasla,	02-Jan-14	27-Sep-16	324178	9.05%
	P.O. R.S., Pune - 411024	02-Jan-14	27-Sep-16	192184	9.05%
		27-Aug-12	25-Aug-15	800000	9.00%
		07-Mar-12	07-Mar-17	200000	9.25%
		07-Mar-12	07-Mar-17	150000	9.25%
		08-May-13	08-May-16	900000	9.00%
		02-Jul-13	02-Jul-16	500000	9.00%
	Total FD amount with Canara Bank			**₹ 3216362**	
2	State Bank of India, DIAT,	28-Jun-15	28-Jun-16	444215	9.00%
	Girinagar, Pune-411025	08-May-13	08-May-16	100000	8.75%
	Total FD amount with State Bank			**₹ 544215**	
	Grand Total			**₹ 3992603**	

(Rupees Thirty nine lakhs ninty two thousand six hundred & three only)

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