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DINAS PERTAMBANGAN DAN ENERGI
PROVINSI NAGGROE ACEH DARUSSALAM
REPUBLIC OF INDONESIA

SHALLOW SHEAR-WAVE REFLECTION SEISMIC APPLICATIONS IN THE KRUENG ACEH RIVER DELTA

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Summary

As part of the project "Management of Georisk" (MANGEONAD) of the Federal Institute for Geosciences and Natural Resources (BGR), Hannover, high resolution shallow shear wave reflection seismic was applied in the Indonesian province Nanggroe Aceh Darussalam (NAD), Sumatra, in cooperation with the Government of Indonesia and the local counterpart Dinas Pertambangan dan Energi of NAD.

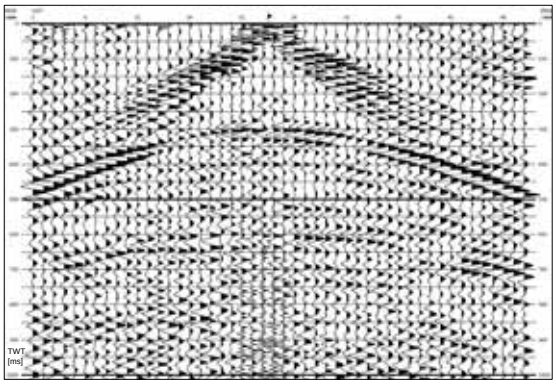
The investigations should support earthquake site effect classification for the reconstruction process and the groundwater exploration activities with the main focus on the city of Banda Aceh and the surrounding region of Aceh Besar. The shear wave seismic investigations were combined with standard geoengineering techniques like Cone Penetrometer Testings for a comprehensive site evaluation and have been supplemented partly by shallow P-wave seismic applications for the derivation of elastic subsurface parameters and the detection of groundwater spots.

Results show that high resolution shallow shear wave seismic is a useful tool to evaluate the subsurface stiffness in terms of International Building Codes for local site effect analysis. Furthermore, due to the resulting depth penetration of 100 m and more, this method leads to a better understanding of the sedimentation process for the Krueng Aceh river basin and can help to identify possible aquifer layers.

Fig. 1: Cut out of the official geologic map (1981) of the Krueng Aceh river delta showing undifferentiated alluvial sediments of holocene age for the whole investigation area. Post tsunami groundwater exploration drillings yield stacks of organic clay, silt, sand and gravel down to a depth of 220 m without any hints of the basement contact.

Fig. 2: Shallow shear wave site investigation at Plang Padang place, centre of Banda Aceh city. Foreground: 48 channel Geode system used for seismic data acquisition. Middle: Local mud zone indicating local subsidence of young sediments. Background: Small houses of nearly traditional Indonesian building style are only minor affected by earthquake shakings. By contrast, the high concrete building shows heavy structural damages up to total collapse due to the earthquake shakings of 26th Dec. 2004.

Fig. 3 (below): Profile location SMK_Negeri: As usual in Banda Aceh, man made land fillings up to 2 m have been done prior to reconstruction activities after the earthquake and tsunami disaster of Dec. 2004 to get mud free areas around the buildings. Subsequent compaction of filling material leads to higher surface shear wave velocities than in the subsurface beneath.



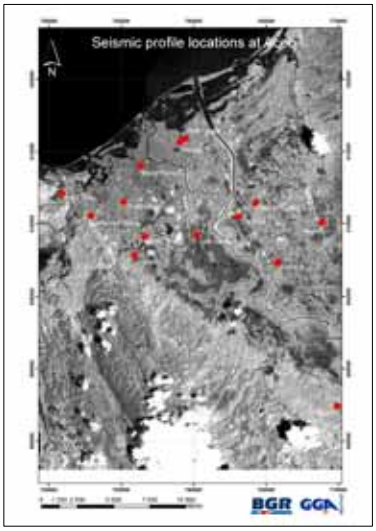


Fig. 4 (above): Location map of seismic profiles.

Fig. 6 (left): Example of correlated SH-wave raw record at profile location Lam Saiun (2 m geophone interval, 96 m total spread) showing a clear shear wave reflection hyperbola of 135 m/s RMS velocity at 300 ms zero offset. This corresponds to a low velocity layer thickness at least of nearly 20 m. Following hyperbola curvatures below indicate no important increase of velocities for greater depths. Furthermore, any kind of refracted waves and especially the often disturbing LOVE surface waves are missing, probably due to a thin, man made high velocity layer at the surface.

Fig. 7 (below): Improvisational open air truck repairs and heavy truck traffic beside shear wave seismic measurements at profile location Babah Jurong giving an insight of the sometimes incalculable difficulties during surveying in the Banda Aceh region. Since people take it mostly by sereneness, problems often disappear after short times.

Acquisition parameters

Period:	20th Nov. – 12 Dec. 2005
Instrument:	GEOMETRICS GEODE
Channels/rec:	48
Shot Locations:	49
Seismic Source:	GGA wheel barrow mounted shear-wave source system
Sweep Type:	20-200 Hz linear, 10 s, 100 ms Taper at both sides
Recording:	12 s (2 s after correlation)
Sampling int.:	1 ms
Recording filter:	out
Spread type:	2D variable split spread, SH-SH configuration, fixed receiver setup
Geophone type:	SM 6H (10 Hz), single units
Receiver int.:	2 (1) m
Source int.:	2 (1) m
Vertical stack:	4-fold [+2Y]-[-2Y] alternated vibrations

Fig. 5 (above): Committed local counterpart ladies carefully executing seismic operators job during data acquisition. The measurements were mostly observed by a lot of interested local people. A ruggedized operator laptop (left above) was a good choice for the often harsh and wet environment conditions in the Aceh region. The „red button stick" has been used for the remote start of the vibratory shear wave source by the operator during a low noise time window.

Fig. 8 (below): The successful local counterpart shallow seismic surveying staff: Munzir Quadry, Dahlan, Ahrufan Ghalba, Syarifah Azharni, Zainudin, Umar, Ilyas and Idawati Arsyad.

Acknowledgements

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All photos courtesy Guenther Druivenga.

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Results

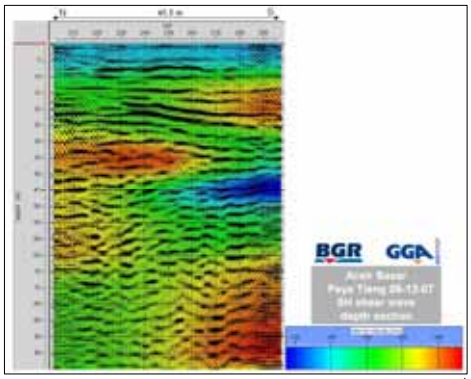

Fig. 9: Profile Paya Tieng: Vav30 = 174 m/s, IBC class S_E (Su<23.9 kPa), soft soil, folded sediments.

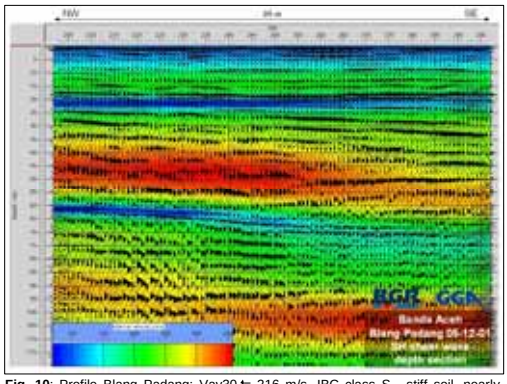

Fig. 10: Profile Blang Padang: Vav30 = 216 m/s, IBC class S_D, stiff soil, nearly horizontally layered sediments.

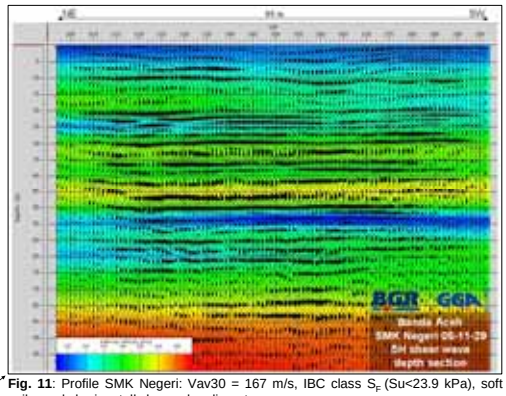

Fig. 11: Profile SMK Negeri: Vav30 = 167 m/s, IBC class S_E (Su<23.9 kPa), soft soil, nearly horizontally layered sediments.

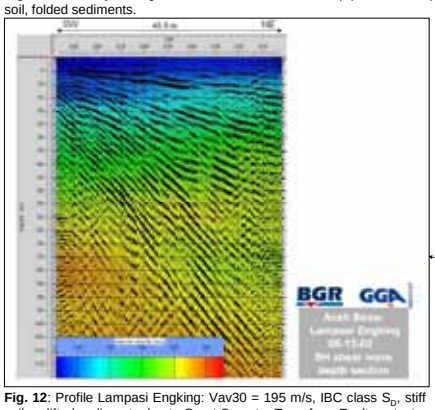

Fig. 12: Profile Lampasi Engking: Vav30 = 195 m/s, IBC class S_D, stiff soil, uplifted sediments due to Great Sumatra Transform Fault contact.

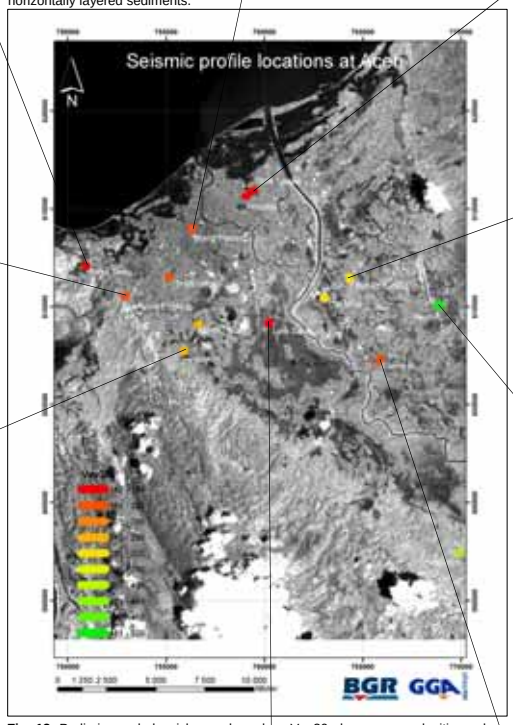

Fig. 13: Preliminary shake risk map based on Vav30 shear wave velocities only. Critical soil conditions were detected for areas near the coastline, especially east of the Krueng Aceh river. Obviously, further critical areas are near the river bed in the south east part of the basin, which has not been expected previously. The negative „highlight" at location Lam Saiun requires an expanding investigation, because this area is close to the intended new urban area.

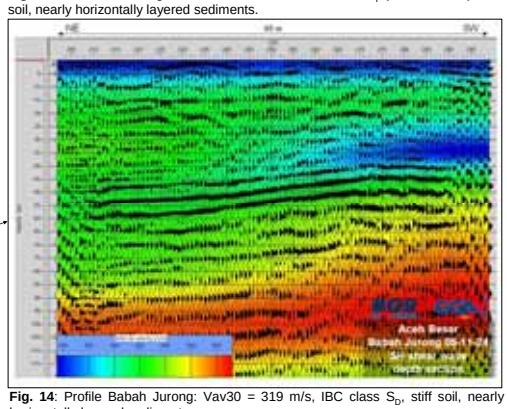

Fig. 14: Profile Babah Jurong: Vav30 = 319 m/s, IBC class S_D, stiff soil, nearly horizontally layered sediments.

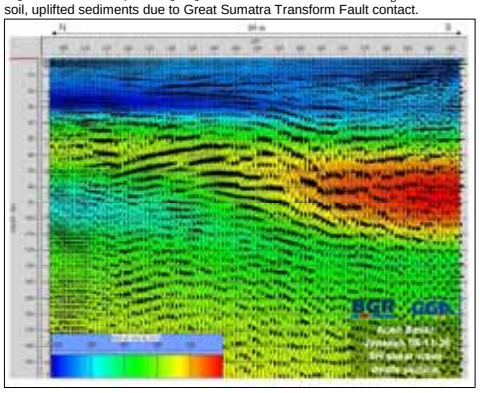

Fig. 15: Profile Japakeh: Vav30 = 247 m/s, IBC class S_D, stiff soil, folded sediments.

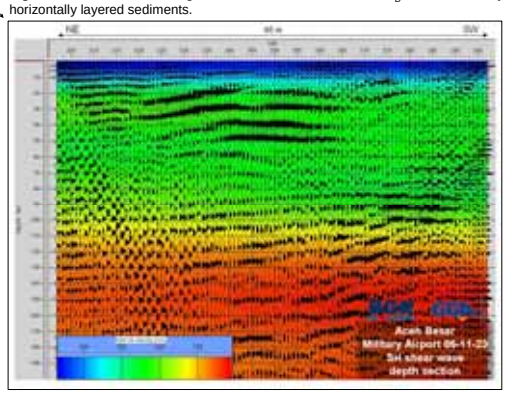

Fig. 16: Profile Military Airport: Vav30 = 497 m/s, IBC class S_C, very dense soil, nearly horizontally layered sediments.

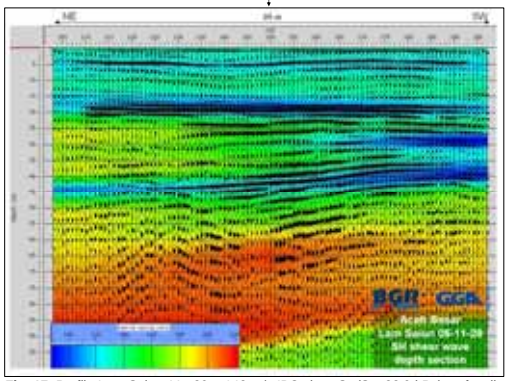

Fig. 17: Profile Lam Saiun: Vav30 = 142 m/s IBC class S_E (Su<23.9 kPa), soft soil, nearly horizontally layered sediments.

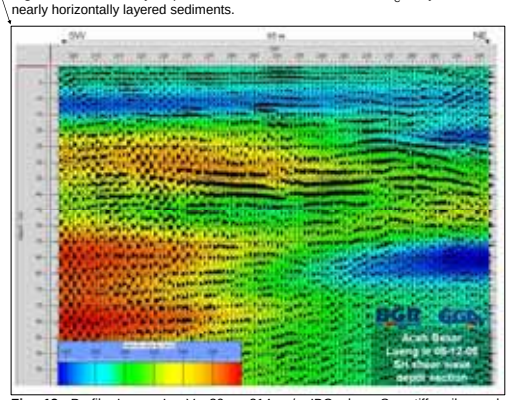

Fig. 18: Profile Lueng Ie: Vav30 = 214 m/s IBC class S_D, stiff soil, nearly horizontally layered sediments.

Conclusions

The seismic site effect evaluation by shallow high resolution seismic investigations was a useful method in the sedimentary regions of the Aceh province and could be successfully applied.

Especially shallow shear wave reflection investigations were able to explore the subsurface stiffness up to 100 m in high resolution leading to geotechnical site classifications in terms of the IBC 2003. Beyond this, the results are also useful for detailed insights in the basin sedimentation processes of the Krueng Aceh river delta, concerning the exploration of new areas for save building foundation and groundwater aquifer detection.

Using a small vibratory seismic source, this technique was applied successfully in areas of high site density in the city of Banda Aceh and also in areas of compacted surface soil like farm tracks in the surrounding, mostly agricultural environment. Obviously, the man made land fillings lead to decreasing velocity gradients at the surface, yielding an efficient suppression of Love surface waves and refracted S-waves in the SH-wave recordings. This results in a clearly increasing S/N ratio of the reflected wave field and therefore much better conditions for the data processing. Whole seismic data acquisition was supported by staff people from the local office of the Dinas Pertambangan dan Energi, Provinsi Nanggroe Aceh Darussalam, some field help and drivers subsequent to an initial training by doing.

The resulting seismic depth sections show a lot of differences within the holocene Krueng Aceh basin sediments. Near the north coast in the area of Banda Aceh city mostly horizontally layered soft to very soft sediments were detected. Sediments in the western part seem to be folded, which is probably due to the tectonic activities near the Great Sumatra fault zone. The south east part of the basin near the volcanics seems to be uncritical in terms of earthquake site effects. Further investigations are required concerning low velocity spots in the basin centre.

SITE CLASSIFICATION

The site classification systems considered in this study are the International Building Code (IBC 2003) system (International Code Council 2003).
The IBC system is based on the average shear wave velocity over the top 30 m (Vav30).

Soil classification by shear wave velocity and material properties:

		Average Soil Properties for Top 30 m (100 feet)		
Soil Type	**Soil Name**	**Shear-wave Velocity, Vs (m/s)**	**Standard Penetration Test, N (blows/foot)**	**Undrained Shear Strength Su (kPa)**
S_A	Hard Rock	>1,500	not applicable	not applicable
S_B	Rock	760 to 1,500	not applicable	not applicable
S_C	Very Dense Soil and Soft Rock	360 to 760	>50	>100
S_D	Stiff Soil	180 to 360	15 to 50	50 to 100
S_E	Soft Soil	<180	<15	<50
S_F	Su < 23.9 kPa - Soil requiring site-specific evaluation			
A site also may be classified as soft soil if more than 3 m of soft clay is present.				

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