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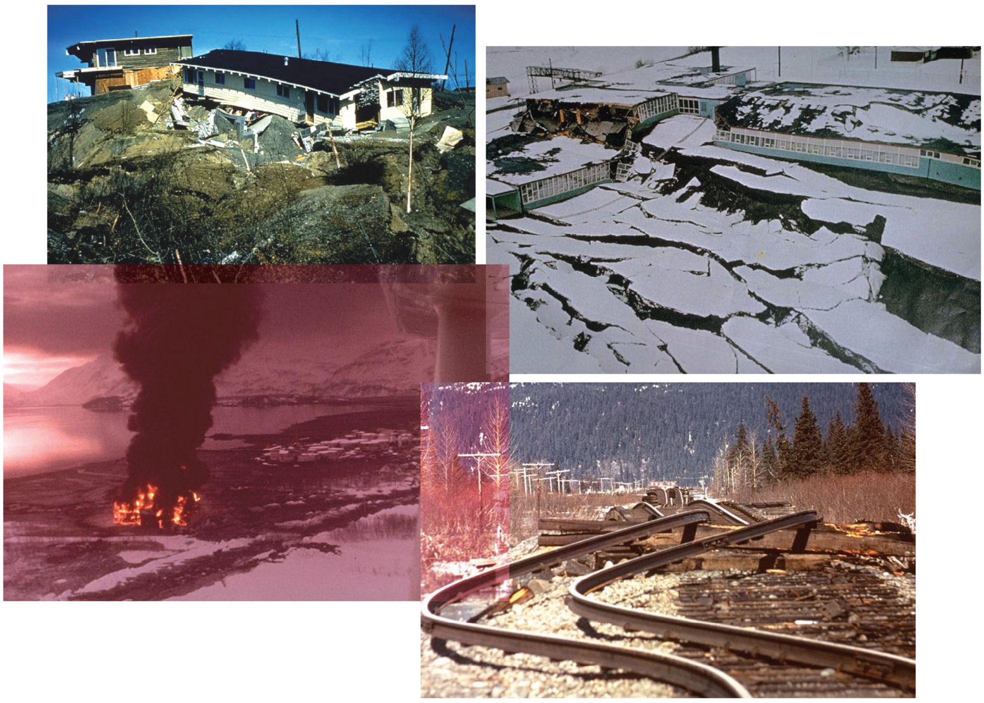

Anchorage, Alaska

June 26th - 27th, 2002

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U.S.—Japan Seminar on Seismic Disaster Mitigation in Urban Area by Geotechnical Engineering
June 26-27, 2002
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Extended Abstract for the Presentation:

An Overview of the Great Alaska Earthquake of 1964

by S. J. Brandenberg[1], & I. M. Idriss[2]

TECTONICS AND SEISMICITY

The largest earthquake in recorded North American history occurred Friday, March 27th at 5:36 pm local time with an epicenter about 130 km east of Anchorage. It had a moment magnitude of 9.2, and the depth of the hypocenter is estimated at 12 to 31 miles (Plafker 1971). The shock was felt over 7,000,000 mi^2. One hundred and fifteen lives were lost in the earthquake, which is low for an earthquake of such a large magnitude primarily due to low population density and the fact that the earthquake occurred on Good Friday when schools were empty and offices were deserted.

There were no strong motion recordings within a few hundred miles of the site, but based on eyewitness accounts the duration of shaking is estimated to have been 4 to 7 minutes with strong shaking lasting approximately 2 to 3 minutes (Housner and Jennings 1964; Steinbrugge 1970). Based on patterns of damage and lack of damage to buildings, the peak ground acceleration was estimated as 0.15g to 0.2g. (Housner and Jennings 1964; Shannon and Wilson 1964; Newmark 1965) The earthquake caused tectonic absolute vertical movements ranging from as much as 38 feet of uplift to 7 ½ feet of subsidence (Plafker 1971). Significant landslides occurred in and around Anchorage with the magnitude of permanent ground displacements ranging from relatively small to devastatingly large. Slide 2 shows the location of the epicenter relative to Anchorage, the region where landslides, ground cracking and avalanches occurred, and the limit of human perceptibility.

The primary cause of seismic activity in Alaska is the relative movement of the Pacific and North American plates. The Pacific plate is moving northwestward relative to the North American plate. Along the panhandle and the eastern end of the Gulf of Alaska, the fault mechanism is characterized by high-angle strike-slip faults. At the north end of the Gulf of Alaska, including the Kenai Peninsula, the relative movement is accommodated by underthrusting of the Pacific plate beneath the North American plate. Slide 3 shows the plate boundary and the direction of movement of the Pacific plate relative to the North American plate.

The boundary between the plates where the underthrusting occurs is a northwestward dipping subduction zone. The 1964 Alaska earthquake was a megathrust earthquake, characterized by interplate faulting on the plate interface. The length of the zone that ruptured is about 750 km (Sykes and Quittmeyer, 1981) and the width that ruptured is estimated from 200 km (Sykes and Quittmeyer, 1981) to 360 km (Davies and House, 1979). Slide 4 shows a cross

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section of the subduction zone through Anchorage, and the location and magnitude of earthquakes along the plate boundary.

LANDSLIDES IN ANCHORAGE AREA

A number of landslides occurred in the Anchorage area. The government hill slide north of ship creek impacted an elementary school. The L Street and the Fourth Avenue Slides occurred in downtown Anchorage. The Turnagain Heights slide, southwest of downtown, involved the largest ground movements of the slides in the Anchorage area. Slide 5 shows the locations and areal extent of the landslides caused by the 1964 earthquake in and around Anchorage. Slide 6 is a photo at the head of the Fourth Avenue Slide.

Fourth Avenue Slide

Slide 7 shows a plan view of the Fourth Avenue slide. The grabens and ground cracks are illustrated with dark lines. The slide movement was from south to north (from the bottom of the plan view to the top) toward the bluff along Ship Creek. Slide 8 is a cross-section of the slide mass along D Street. The site consists of a layer of dense sand and gravel about 35 to 40 feet thick overlying a deep layer of bootlegger cove clay. Details of the soil properties are discussed below.

A graben formed along D street, just north of Fourth Avenue. The horizontal movement of the soil mass north of the graben was about 19 feet along a nearly horizontal slip plane. South of the graben, however, the horizontal movement was generally less than ½ foot. Slide 9 shows a cross section of the slide mass along B Street.

Two grabens developed along B Street, in which vertical movements of up to 10 feet were measured. Horizontal movement of up to 19 feet was observed in the soil mass downslope of the first graben, and up to 11 feet in between the two grabens. Behind the second graben, movement was generally less than ½ of a foot.

Slide 10 shows a cross section along Barrow Street, east of the slide. There were no appreciable movements along this section in 1964.

In 1982, the State of Alaska was planning to build a major State Office Complex near the Fourth Avenue Slide of 1964, and engaged Woodward Clyde Consultants to conduct subsurface investigations and to reevaluate the 1964 slide.

The upper 35 to 40 feet consist of very dense gravels and sands with SPT blow counts that typically exceed 60 bpf. Below the dense sand and gravel lies an interbedded zone consisting of alternating layers of clays, silty sands and sandy silts that extend to a depth of about 65 feet below the surface. The interbedded layers are relatively thin (about ±1 to 10 ft) and do not appear to be continuous. The portion of the Bootlegger Cove Clay in the interbedded region is stiff to very stiff and is moderately overconsolidated. A uniform layer of lightly overconsolidated Bootlegger Cove clay underlies the interbedded zone to the maximum depth explored (150 feet below the ground surface). Slide 11 shows the soil conditions observed in the 1982 site investigation. An objective of the 1982 site investigation was to determine whether the Fourth Avenue Slide was caused by liquefaction of silty sand and sandy silt in the interbedded layers, or undrained failure of the Bootlegger Cove Clay.

Slide 12 shows the SPT blow counts from the silty sand and sandy silt in the interbedded zone. N1-values in the silty sand layers range from 21 to about 105 bpf, and N1-values in the sandy silts from 16 to 50 bpf. For liquefaction evaluation, the N1-values in the sandy silt layers were increased by 7.5 since the median grain size was less than 0.15 mm. Slide 13 shows the liquefaction potential in the sandy soil in the interbedded zone. The line separating the liquefaction region from the no liquefaction region has been scaled from M=7.5 to M=9.2. The minimum factor of safety against liquefaction was 1.6, which indicates that liquefaction of these soils was unlikely during the 1964 earthquake (Idriss 1985).

The Bootlegger Cove Clay layers in the interbedded zone are stiff to very stiff with OCR ranging from 3 to 4. Fluctuations of lake level during glaciation and subsequent drainage of the lake probably exposed the sediments to subaerial conditions, resulting in increased strength. Slide 14 shows the OCR of the Bootlegger Cove clay vs. depth below the interbedded layers. The Bootlegger Cove Clay below the interbedded zone is uniform with OCR ranging from 1.2 to 1.5. The SHANSEP (Stress History and Normalized Soil Engineering Properties) was used to evaluate the in-situ undrained shear strength of the clay. Slide 15 shows the peak undrained shear strength from direct simple shear tests performed on samples of the Bootlegger Cove clay. The normalized strength was related to the OCR by $\frac{S_u}{\sigma'} = 0.19 \cdot (OCR)^{0.78}$. Slide 16 shows results of cyclic direct simple shear tests. The soil was loaded cyclically until a predetermined excess pore pressure was obtained, then it was monotonically sheared undrained to failure. At $r_u = 0.9$, the strength of the clay was found to be 70% to 75% of the peak undrained shear strength. The residual strength of the clay was estimated to be about 30% of the peak undrained shear strength from results of miniature vane tests, CPT tests and direct shear tests (Idriss 1985).

A Newmark sliding block analysis was performed to determine whether the movements measured at the Fourth Avenue slide could be attributed to undrained failure of the Bootlegger Cove clay. Slide 17 shows the undrained shear strength vs. ground displacement that was used in the analysis. For ground displacements less than ½ ft, the peak undrained shear strength was used, and was decreased with each cycle to account for the influence of excess pore pressure. When ground displacements exceeded ½ ft, the residual strength was used. The peak undrained shear strength was varied until displacement from the analysis matched the measured displacement for each soil mass. Slide 18 shows the undrained shear strength from displacement analysis compared with the undrained shear strength estimated to have existed in 1964. There is good agreement between the undrained shear strengths, indicating that the Fourth Avenue slide was caused by undrained failure of the Bootlegger Cove clay (Idriss 1985).

The Fourth Avenue Slide and the L Street Slide both involved significant soil movement, and were separated by a zone of no appreciable movement in 1964. The bluff area at the northwest corner of downtown near the courthouse did not slide during the 1964 earthquake. The OCR of the Bootlegger Cove Clay in this region ranged from 2.2 to 3.4 with an average of 2.7. In contrast, the average OCR at the Fourth Avenue slide was 1.4, and at the L Street slide was 1.7 (Idriss 1985, Moriwaki et al 1989, Woodward-Clyde Project files for the courthouse study). The variation of OCR at the three locations is shown in Slide 19. The higher undrained shear at the courthouse site (relative to the Fourth Avenue slide and L Street slide areas) was sufficient to prevent sliding in 1964.

Turnagain Heights Slide

Slide 20 shows a plan view of the Turnagain Heights slide. The slide extended over 8000 feet from west to east along the bluff line, and retrogressed inward up to 1200 feet at the west end and 600 feet at the east end. The area of the slide was about 130 acres. Lateral movement of the slide was as much as 2000 feet. The west end of the slide was undeveloped, and the east end of the slide was a residential area. According to eyewitness accounts, the slide began about 2 minutes after the start of shaking and continued after shaking had ceased. (Seed & Wilson 1967)

Earthquake Park was built at the west end of the slide to commemorate the 1964 earthquake.

Slide 21 is a photo at the east end of the slide after the earthquake. Within the slide area the ground was broken up into a complex system of ridges and depressions, and average vertical drop in depressed areas between ridges was 35 feet. 75 homes were destroyed at the east end of the slide. An occupant of one of the houses in the slide area explained "The floor ripped and sand came up from below into the living room," which indicates that liquefaction occurred during the earthquake (Seed & Wilson 1967).

Slide 22 shows the soil conditions at the east end of the slide. The site conditions generally consisted of a surface layer of dense sand & gravel ranging in thickness from 15 to 20 feet at the east end to 5 to 10 feet at the west end. The sand and gravel deposit is underlain by a deep bed of Bootlegger Cove clay about 100-feet to 150-feet thick. The Bootlegger Cove clay is a marine deposit with shear strength decreasing from about 1 tsf at its surface to 0.45 tsf at El. 0, and then increasing again to about 0.6 tsf at El. -30. The clay contains numerous seams of silt and fine sand that are discontinuous ranging in thickness from a fraction of an inch to about 3 feet, but generally not more than several inches. Below El. 10, the sand lenses were less frequent. Seaward of the bluff line the clay was overlain by a layer of estuary silt that sloped gently downward away from the coastline. This material would tend to liquefy during earthquakes and was judged to have played an important role in the development of the slide (Seed & Wilson 1967).

Slide 23 shows results of cyclic direct simple shear tests performed on the Bootlegger Cove clay. For 30 significant cycles, such as might have been developed during the earthquake, failure was induced by a cyclic stress equal to about 55% of the static strength. For the soft sensitive clay with an in-situ static shear strength of about 850 psf, the cyclic shear strength would be about 470 psf (Seed & Wilson 1967).

Slide 24 shows results of cyclic triaxial compression tests, corrected for simple shear conditions, performed on sand from the lenses in the clay. A cyclic shear stress of about 420 psf would be required to cause liquefaction in 30 stress cycles. The cyclic shear stress required to cause liquefaction of the sand is less than required to cause failure of the soft clay; hence, it is reasonable to conclude that liquefaction of the sand seams would precede failure of the clay (Seed & Wilson 1967).

A 1000-ft trench extending from the back of the slide zone to beyond the toe of the original bluff line was excavated on the east side of the slide to observe the distribution of materials in the slide zone. Slide 25 illustrates the findings from the trench excavation. The landslide was primarily translational along a slip surface inclined about 4^o downward toward the original toe of the bluff. Clay ridges and depressed grabens were a characteristic feature of the slide area. The ridges underwent large displacements with nearly no change in inclination, and the average vertical displacement of the depressions was 35 feet. The grabens were sometimes inclined downward toward the original bluff line, and sometimes upward toward the head of the slide, indicating a complex slide mechanism.

Seed & Wilson describe the likely slide mechanism, which is paraphrased as follows. Shaking caused liquefaction of the sand lenses at about 5 to 25 feet elevation some distance behind the bluff. The liquefied zone retrogressed backward from the temporarily stable bluffs. As a result of inertial forces and loss of strength of the soil, failure developed at the bluffs as a result of a conventional slide mechanism. The slide material was deposited on the sloping liquefied estuary silt, which carried it downslope, exposing the slide surface and permitting a second slide of the same type. After one or more such slides, the sliding surface merged into the previously weakened zone behind the original bluff line, and the mechanism changed from rotational to translational. The slide then developed quickly, resulting in ridges in the clay and severely depressed grabens. At this time the sliding involved translation on the liquefied sand lenses, but also involved extensive shear zones through the clay as it was remolded. The slide mass moved quickly toward the bay on the liquefied silt. When shaking stopped, the silt and sand lenses probably stabilized and inertial forces ceased, but sliding continued to progress due to the zones of remolded clay at the shearing surfaces (Seed & Wilson 1967).

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Slide 1

University of California, Davis

Department of Civil & Environmental Engineering

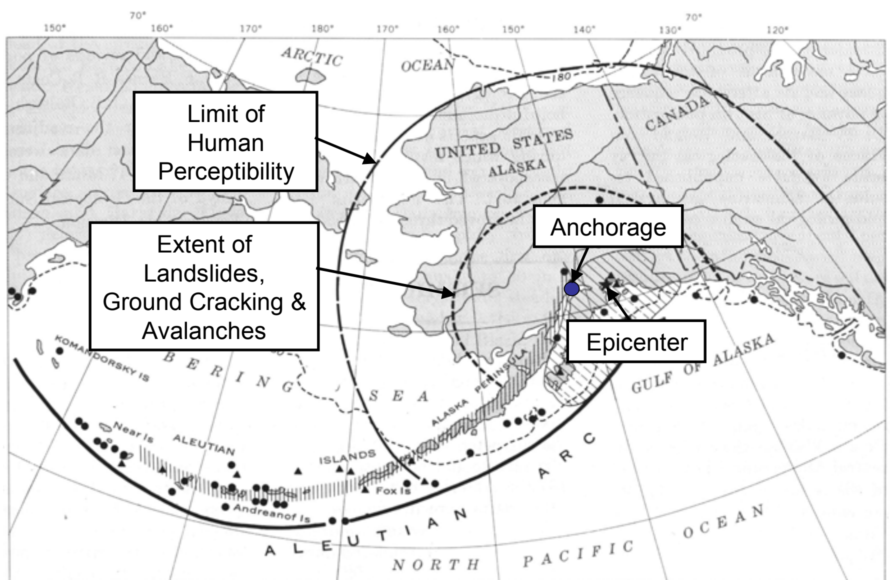
An Overview of the Great Alaska Earthquake of 1964

S. J. Brandenberg

I. M. Idriss

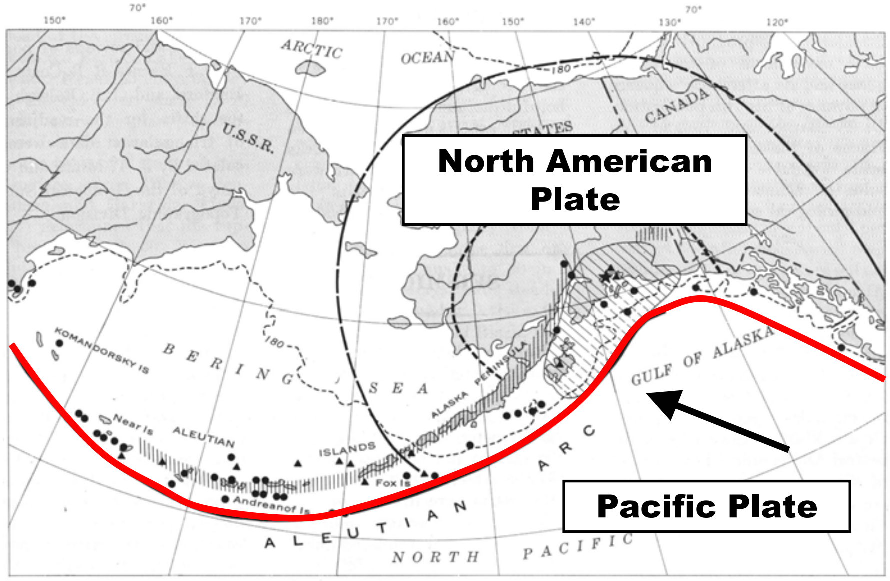
June, 2002

Slide 2



Plafker, 1971

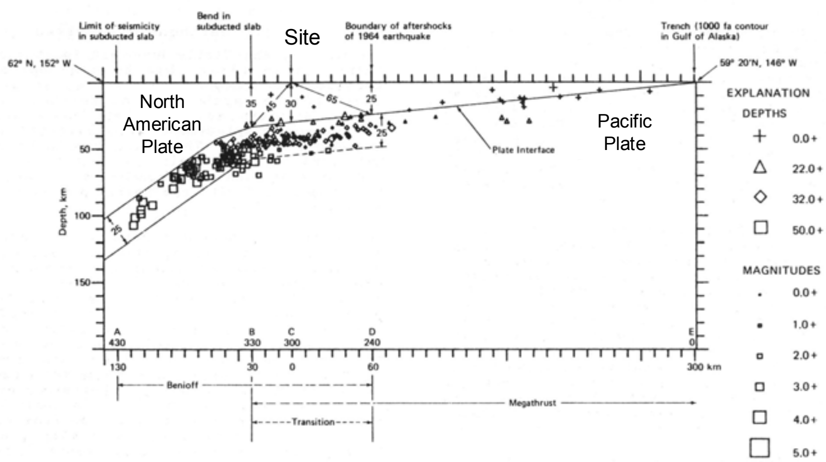
Slide 3



Plafker, 1971

Slide 4

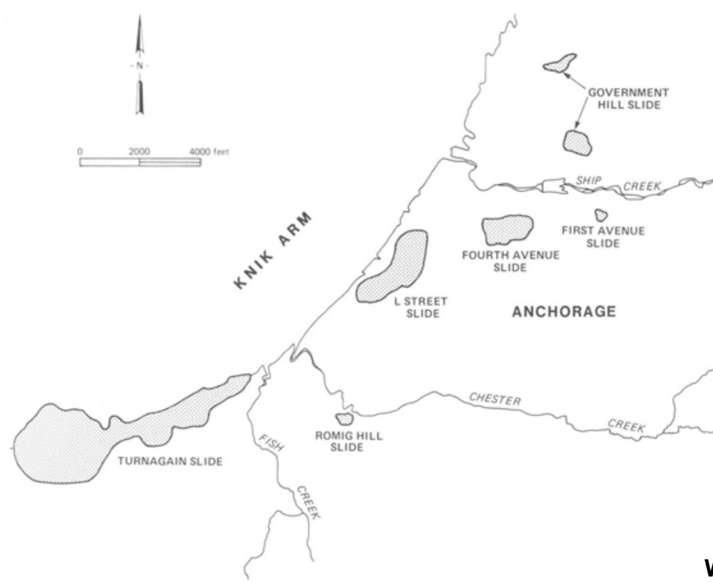
Cross-Section of Subduction Zone Relative to Anchorage



Lahr & Stevens, 1982

Slide 5

Plan View of Landslides in Anchorage Area Caused by 1964 Earthquake



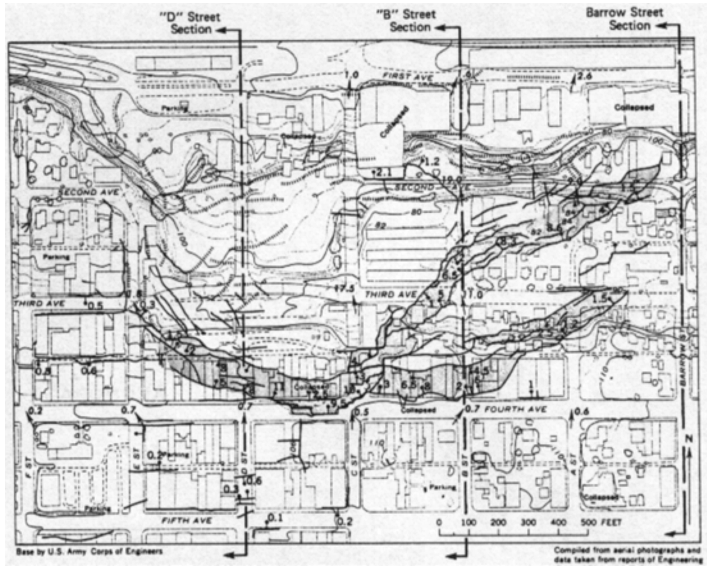
Wilson, 1967

Slide 6

Hansen, 1971

Slide 7

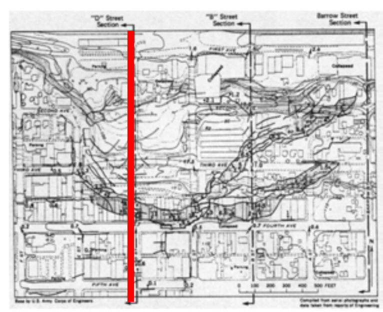
Plan View of Fourth Avenue Slide

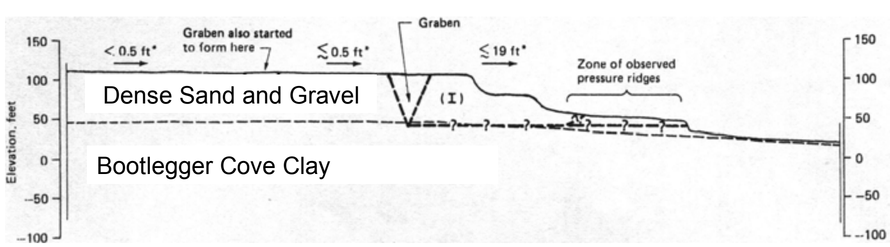


After Long, 1973

Slide 8

Cross-Section of Slide Along D Street

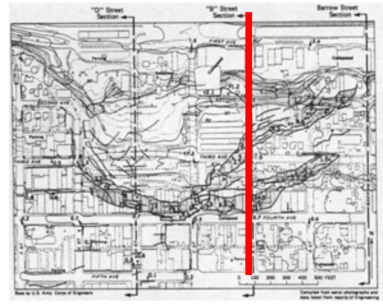


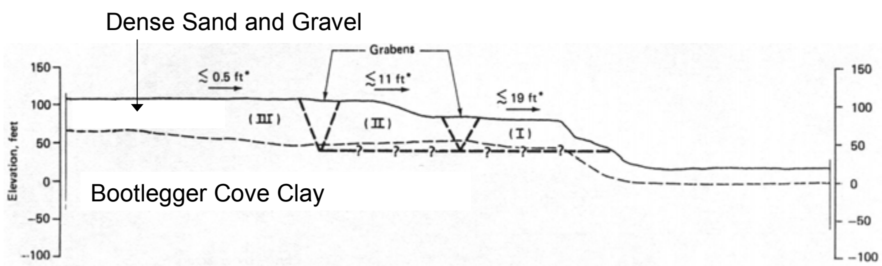


Idriss, 1985

Slide 9

Cross-Section of Slide Along B Street

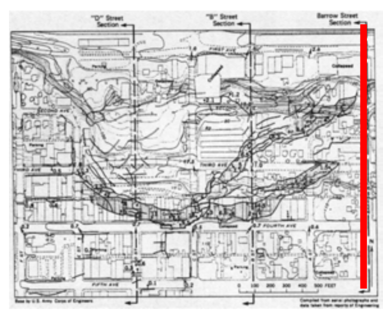


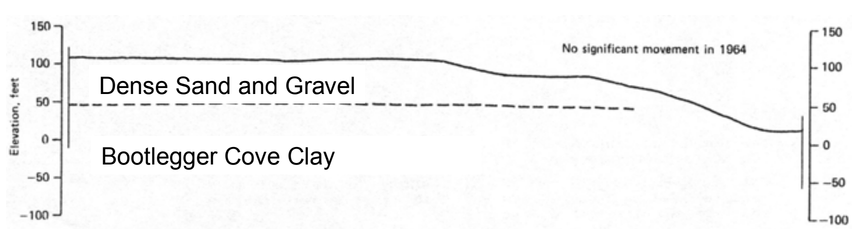


Idriss, 1985

Slide 10

Cross-Section of Slide Along Barrow Street

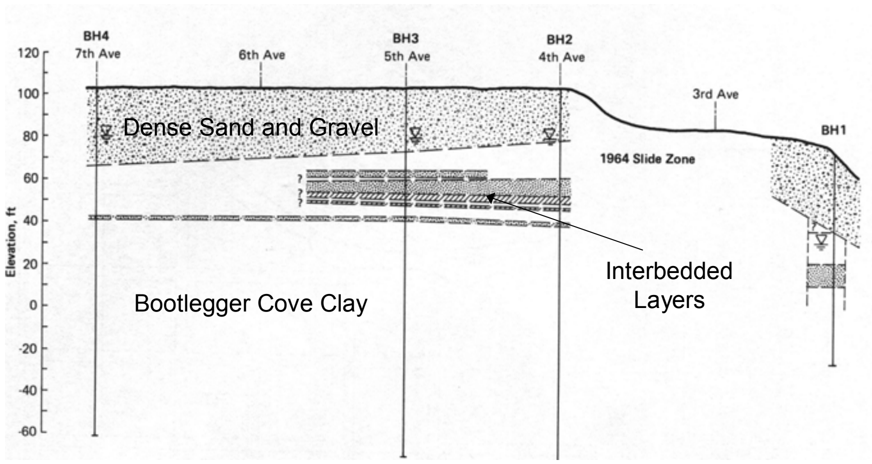




Idriss, 1985

Slide 11

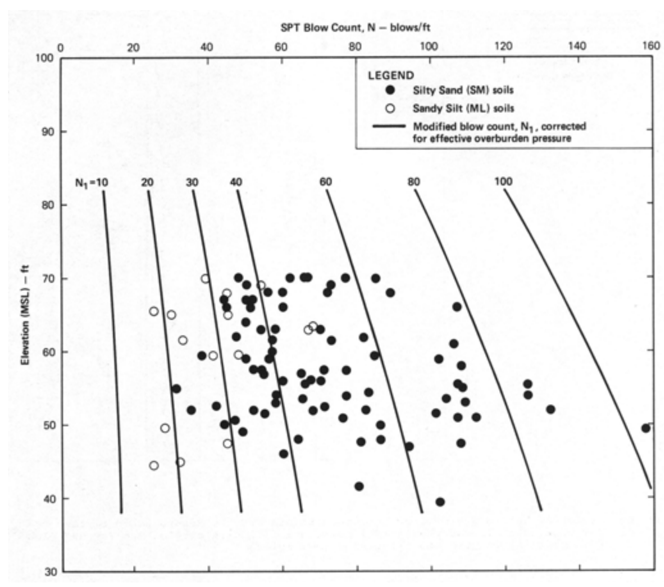
Soil Conditions from 1982 Subsurface Investigation



Idriss, 1985

Slide 12

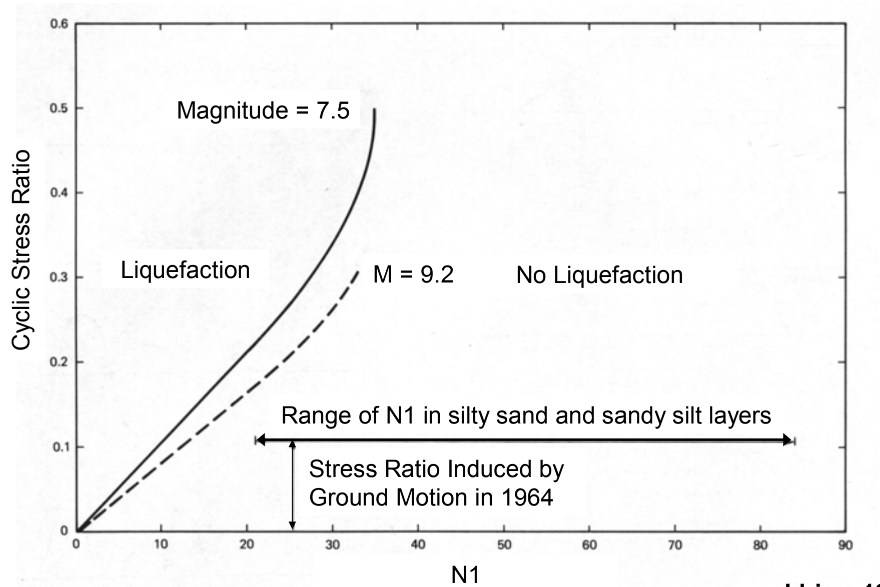
SPT Blow Counts in Sandy Strata in Interbedded Zone



Idriss, 1985

Slide 13

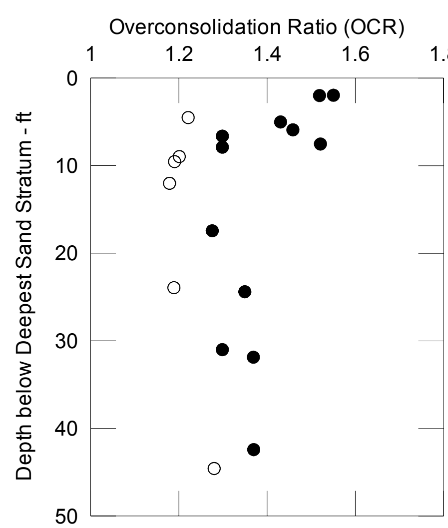
Liquefaction Evaluation of Sandy Strata in Interbedded Zone



Idriss, 1985

Slide 14

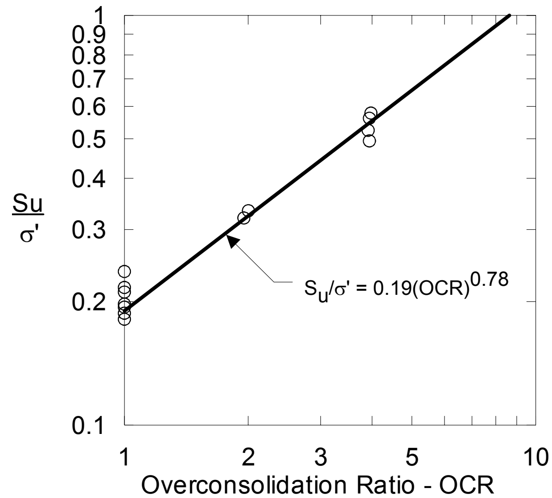
Bootlegger Cove Clay: OCR vs Depth



Idriss, 1985

Slide 15

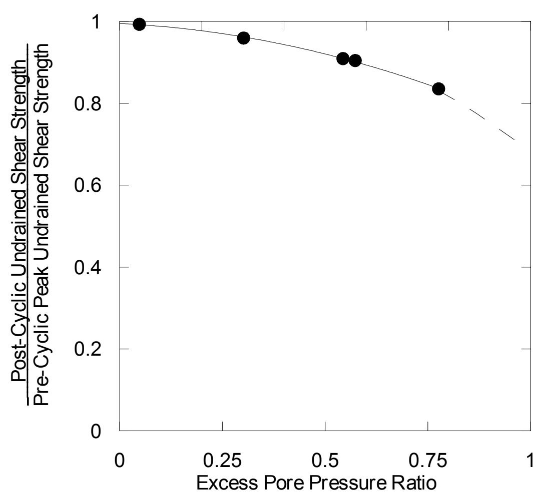
Bootlegger Cove Clay: DSS Test Results



Idriss, 1985

Slide 16

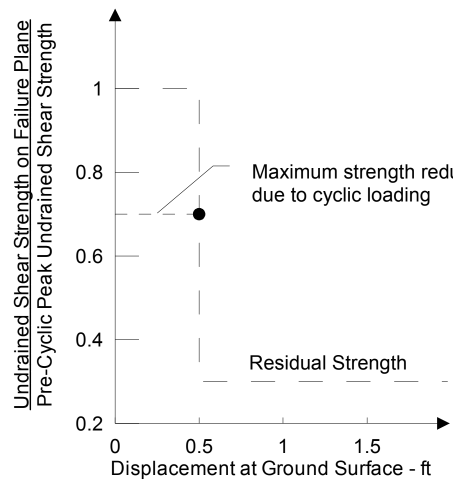
Bootlegger Cove Clay: Cyclic DSS Test Results



Idriss, 1985

Slide 17

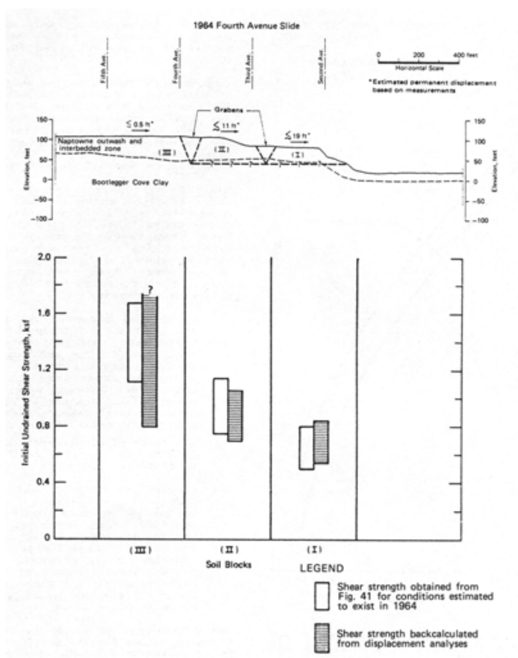
Bootlegger Cove Clay: Normalized S_u for Newmark Sliding Block Analysis



Idriss, 1985

Slide 18

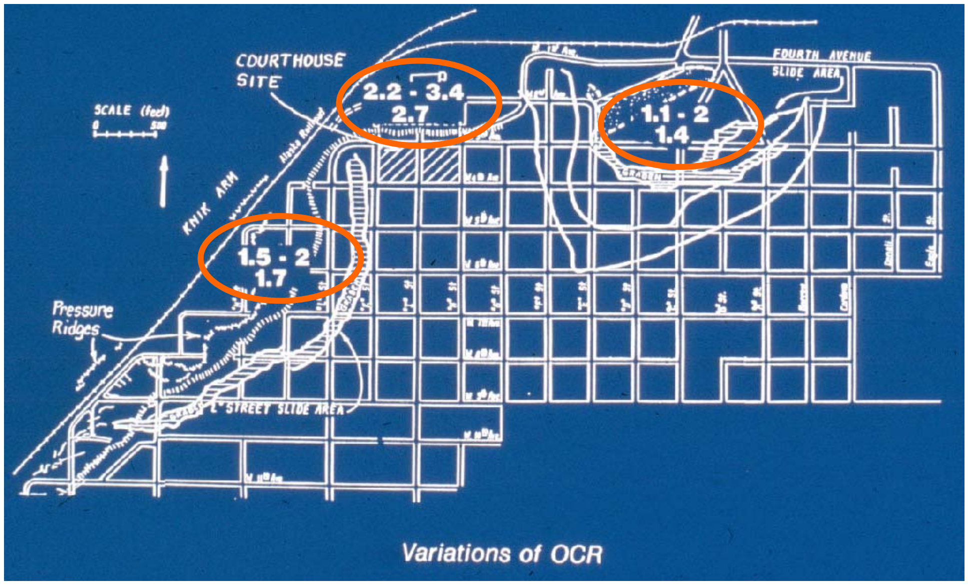
Results of Newmark Sliding Block Analysis



Idriss, 1985

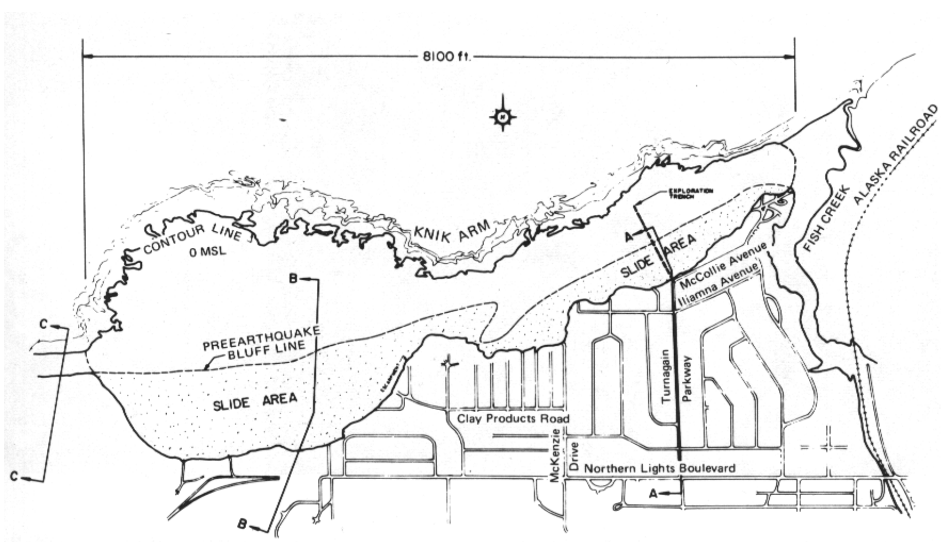
Slide 19

Bootlegger Cove Clay: Variation of OCR with Location in Anchorage



Slide 20

Plan of Turnagain Heights Slide Area

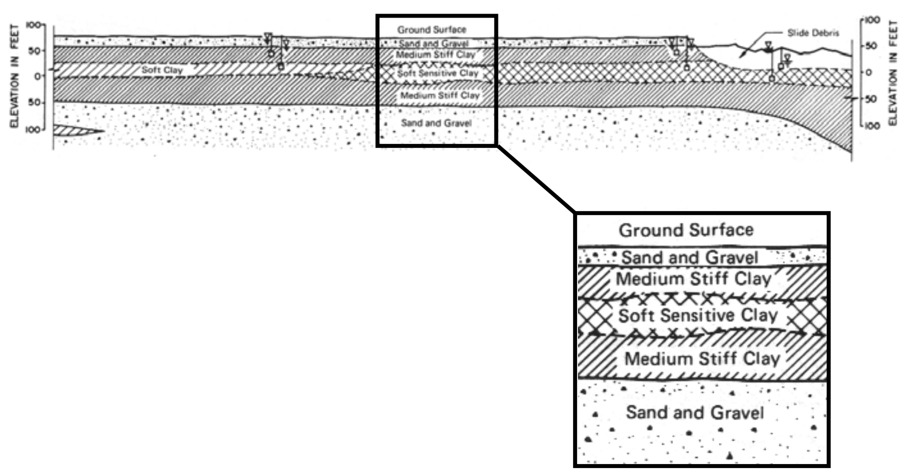


Seed & Wilson, 1967

Slide 21

Slide 22

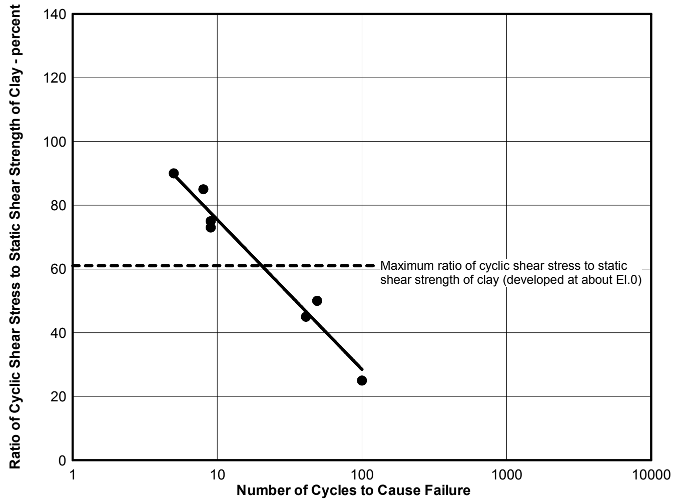
Turnagain Heights Slide - Soil Profile Through East End of Slide Area



Seed & Wilson, 1967

Slide 23

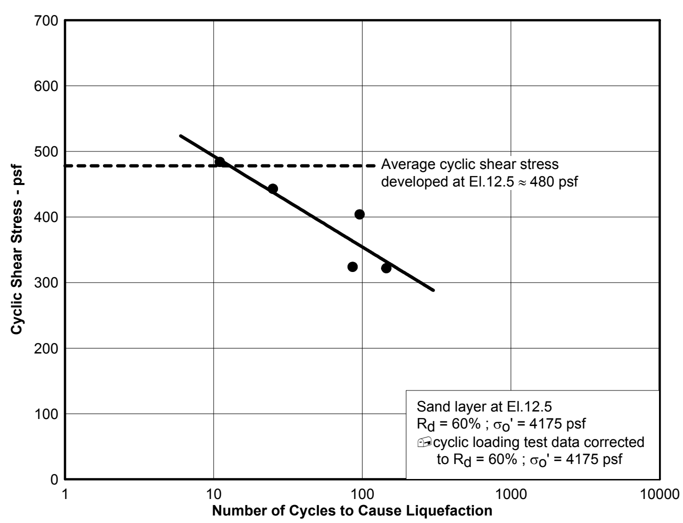
Results of Cyclic Direct Simple Shear Tests of Bootlegger Cove Clay



Seed & Wilson, 1967

Slide 24

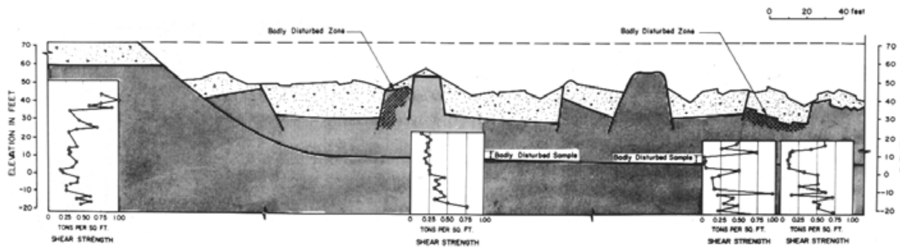
Results of Cyclic Triaxial Compression Tests of Sand from Lenses



Seed & Wilson, 1967

Slide 25

Detailed Soil Profile Through East end of Turnagain Slide



Seed & Wilson, 1967

Slide 26