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Geotechnical Aspects of Seismic Design of Bridges in New York City

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SYNOPSIS Earthquake damage Civil engineering structure and bridges are no exception. Historically, bridges have proven to be vulnerable to earthquakes which cause damage to substructures and foundations and in some cases being totally destroyed as Superstructure collapse from their supporting elements. The bridges in New York City are required to comply with Specifications of American Association of State Highway and Transportation Officials (AASHTO) and New York State Department of Transportation (NYSDOT). The seismic design criteria has been recently introduced in these specifications and all bridge projects in New York City must comply to these requirements. The extent of seismic analysis required varies with bridge's scope of rehabilitation or replacement scheme. The New York City Metropolitan area presents foundation engineers with a wide variety of soil profiles that varies from soft clay to compact glacial deposits. Local bedrock configurations are similarly extremely variable. The thickness and quality of the soil overburden generally plays a significant role in the seismic design of bridges.

The paper summarizes the available geotechnical information regarding seismic design of bridges in New York City and discusses the geology, seismicity, seismic risk, various subsurface soils encountered in the area and their liquefaction potential. Seismic evaluation being performed on several of its important bridges is briefly presented.

INTRODUCTION

Bridges are important links in our transportation network and provide the means for crossing both manmade and natural obstacles. It is essential that they continue to function in this vital role following an earthquake. Earthquakes are probably nature's greatest hazards to life, and highway bridges have been found to be highly susceptible to damage under earthquake loading. The hazards imposed by earthquakes are unique as hazard to life is associated almost entirely with responses of manmade structures like bridges, buildings, dams, etc. Even a successful prediction of this event cannot eliminate the earthquake hazard but can be countered by the design and construction of earthquake resistant structures.

Earthquake hazards also poses a unique engineering design problem as an intense earthquake constitutes the most severe loading to which bridge structures might possibly be subjected and yet the probability that any given structure will ever be affected by a design earthquake is very low. The optimum engineering approach to this combination of condition is to design the structure so as to avoid collapse in the most severe possible earthquake, thus insuring against loss of life, and accepting the possibility of damage. The rationale being that it is less expensive to repair structures which will be damaged by a major earthquake than to build all structures strong enough to elastically resist these seismic loads with no damage. Clearly this design concept presents the engineers with a most challenging problem. New York City bridge design philosophy is consistent with above stated concept.

GEOLOGY

New York City is the largest city in the United States and covers an area of approximately 950 km^2 in the south eastern section of New York State. New York City presently consists of five boroughs - the Bronx, Brooklyn, Queens, Manhattan and Staten Island and straddles parts of three physiographic units: the Atlantic Coastal Plain on the southeast, the New England upland on the northeast, and the Triassic lowland on the southeast.

New York metropolitan area was subjected to an almost unprecedented barrage of one dynamic geological process after another: submergence beneath the sea, sedimentation and crustal subsidence; volcanism; mountain building, metamorphism, long term and deep erosion, more sedimentation, volcanism, etc., continental glaciation, and the post-glacial growth of coastal beaches. Consequently, New York has been molded and remolded into its present form over the immense span of geological time by almost all the agents responsible for bringing about surface change. The New York City Area contains many different rock types and more than a dozen soils units as shown in figure 1.

SEISMICITY

Generally seismic activity is associated with the movement of faults in the area. Most major fault lines in Manhattan and the Bronx trend northwest. Examples are: along Mosholu Parkway in the Bronx, Spuyten Duyvil and the Dyckman Street - Burnside Avenue line between the Bronx & Manhattan, 125th Street from the Hudson River to St. Nicholas Avenue, to and crossing the northeast corner of Central Park, thence to 23rd Street and Pearson Street in Long Island City (Manhattan to Queens), and Wallabout channel in the lower East River to East 17th Street and Avenue A on the lower southeastern side of Manhattan. There are other major fault zones such as paralleling Roosevelt Island. The lower Harlem River follows part of a fault zone that enters the channel from northwest above 155th Street. The direction of movement on New York City faults also varies.

Some faults in New York City are open and act as channels for water flow, others contain gouges or secondary mineralization and are healed. Fort Tryon Park, south of Dyckman Street are examples of both of these faults. The faults described above in the city probably represent many ages of movement. No solid evidence indicates that faulting has taken place in the recent past, although mild earthquakes take place in the city limits from time to time. It has been difficult to determine if the existing faults in the area are active. Active faults are those along which movement has taken place during recorded history and along which movement can be expected at any time.

Generally, the New York City area has been characterized by few earthquakes, and those were of modest to low intensity(I to V on the modified Mercalli scale). Several minor shocks have been caused in the last 20 years by activity along faults either west of the City(Central NJ. to Rockland County, NY.) or along faults in central Westchester County. More research is needed to correlate seismicity with specific faults with New York City. However, the largest earthquake documented in the New York area occurred in 1884. It was located few miles off the southern shore of Western Long Island. The published reports indicate that it toppled chimneys and broke windows from northern NJ. to New York City. The greatest damage was reported on Western Long Island. Another earthquake of similar size occurred in the general area of southeastern NY. in 1737. Both of these earthquakes were assigned a magnitude of approximately 5.9 and 5.1

respectively. Figure 2 shows the occurrence of seismic events in NY. State including New York City. Based on the past seismic activity in the area as discussed above, the following conclusions can be drawn:

1. New York Metropolitan area has experienced earthquakes of magnitude 5 in the past and similar earthquakes can be expected to hit the area in the future.
2. Probability of future earthquakes of larger magnitude than what were experienced in the past cannot be ruled out

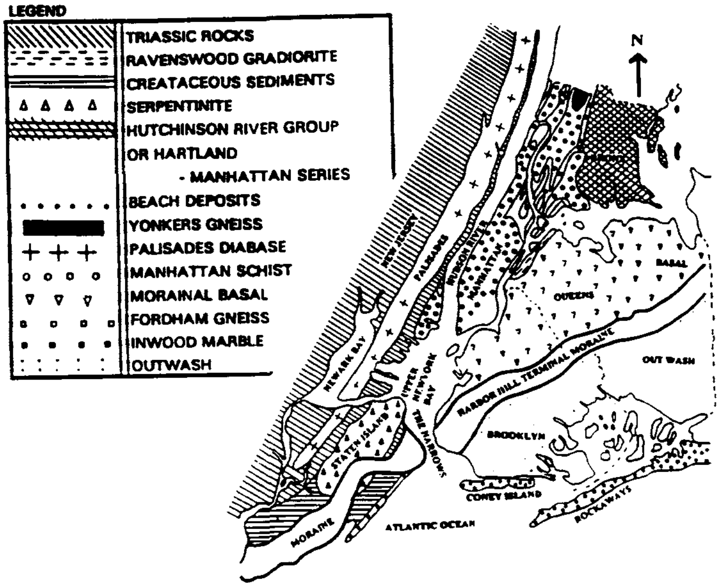

Fig. 1. Geological Map of New York City

Recently, American Association of State Transportation Officials (AASHTO) and the local codes have been revised which require that all new bridges be designed and existing bridges be retrofitted to meet the seismic criteria. New York State Department of Transportation (NYSDOT) has designated New York City in Seismic Performance Category (SPC) B.

Seismic Hazard

Seismic risk is the probability that social or economic consequences of earthquakes will equal or exceed specified values at a site, or at several sites, or in an area, during a specified exposure. Seismic hazard, on the other hand, is any physical phenomenon (e.g. ground shaking, ground failure) associated with an earthquake that may produce adverse effect on human activities.

Seismic risk and hazard statements are essentially forecasts of future situations and they are inherently uncertain. Seismic hazard assessments are attempts to forecast the likely future seismic activity rates and strengths based on knowledge of past and present. To obtain reasonable credibility, considerable knowledge of both historical seismicity and geology need to be used, together with an appropriate analysis of the uncertainties. After both, the estimated future seismic activity rates and the acceptable risks are known, appropriate earthquake loading for the proposed structure may be determined. Depending on the location and nature of the project, seismic risk and hazard evaluation ranging from none through arbitrary to thorough may be required.

In April 1988, Scawthorn and Harris in his report for National Center for Earthquake Engineering Research (NCEER) indicate that if an earthquake of magnitude 6 hits New York City, it would cause $11 billion to $26 billion in damages depending on its epicenter. Dr. Ian Buckle of NCEER in "Civil Engineering News, November 1990" further stated that there would be a great deal of structural damage to all the unreinforced masonry, and more than half of Manhattan is of this kind. Dr. Buckle concluded there would be property losses and high number of injuries and deaths from structural damages, and recommended that retrofit of critical existing structures must be undertaken without delay. NYC DOT Bureau of Bridges has assigned high priority to this task and its bridges are evaluated for retrofit and seismic hazard analysis on a case by case basis complying with AASHTO and NYSDOT guidelines.

INFLUENCE OF SOIL CONDITIONS ON GROUND MOTION AND STRUCTURAL DAMAGE

The damage resulting from earthquakes may be influenced in several ways by the characteristics of the soils in the effected area. Deposits of loose granular soils may be compacted by the vibrations induced by the earthquake resulting in large settlements and differential settlements of the ground surface. The tendency to compact may result in the development of excess hydrostatic pressure of significant magnitude which may cause liquefaction of the soil resulting in settlements and tilting of the structures. The combination of dynamic stresses induce pore water pressures in deposits of soft clays and may result in major landslides. A somewhat less obvious effect of soil conditions on structural damage is the influence they exert on the intensity of ground shaking and associated structural damage which may develop even though the soils underlying a structure may remain perfectly stable during an earthquake. New York City soils and their effects during earthquake are discussed below.

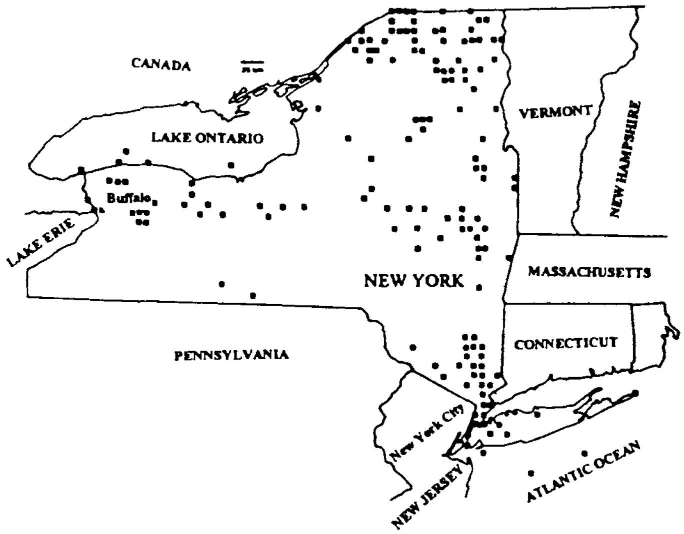

Fig. 2. Map of New York State showing New York City, and the location of Historical Earthquakes between 1737 and 1937

Soil Profile Type

AASHTO seismic criteria require that subsurface profile beneath the substructure be established to obtain the appropriate geotechnical parameters for structural design. The New York City Department of Transportation, Bureau of Bridges recommends to perform site specific subsurface investigation for seismic structural design and evaluation of functionally important bridges. The effects of site conditions on bridge response are determined from a site coefficient S, based on soil profile type S1, S2, or S3.

S1: Includes bedrock with stable deposits up to 66 meter thick.
S2: Stable deposits in excess of 66 meter.
S3: Soft surface deposits (clays & peat) and other unstable deposits at least 10 meter thick.

A brief general description of various soil types encountered in New York City area and their characteristics are summarized below:

Refer to Figure 1, at the west end of Brooklyn, the upper soils typically consist of very loose sands and much of the area has been reclaimed from the bay by dumping and filling. These sands in conjunction with the high water table are extremely susceptible to vibratory loading. Experiences with vibratory pile driving in the area indicate that these soils are very susceptible to large settlements and loss of capacity even from low level of shaking. Such behavior indicates that structure founded on these soils are susceptible to major damage for even mild seismic events. Away from this region the soils in the Brooklyn area are generally dense sand and gravel. At the southern end of the borough, the sands extend to a depth of several hundred feet. The soils in Brooklyn may range from soil profile S1 to S3.

In both Queens and the Bronx, alongside the Long Island Sound, the upper soils are extremely soft silts, clays and peat which can extend to great depths with relatively high ground water table. These soft soils may be underlain by loose fine sands which may behave peculiarly during a low seismic event. Since major structures in the area are often supported on friction piles relying on their sides for support, these structures may be effected by low level events. In the Bronx the soft silt /clays are typically not as thick as in Queens and are underlain by bedrock. The soil in Bronx again can range from S1 to S3. In Manhattan the vast majority of the area indicates bedrock at or near the ground surface, with the exception of narrow zones along river banks. In these zones the soils are highly variable. Most of the part, soil profile in Manhattan may consist of S1 to S3.

Due to complex soil condition in New York City area the revised codes may modify existing soil classifications and perhaps shall include additional soil classification category S4.

Liquefaction

One of the most dramatic causes of damage to engineering structures during earthquakes has been the development of liquefaction in saturated granular deposits. Liquefaction is the loss of strength of saturated cohesionless soils subjected to shear stresses large enough to cause relative movement of the soil grains into a more compact configuration under conditions where the pore water cannot readily escape. Liquefaction is generally manifested either by the formation of boils at the ground surface and in some cases by the development of quicksand - like conditions over affected area. There are theoretical as well as empirical approaches to analyze and evaluate susceptibility of soils to liquefaction. Factors affecting the choice of alternatives include the relative cost of additional analysis and remedial measures, probable risk to life and property, and functional importance of the project.

Empirical analysis generally correlate observed cases of Liquefaction and non-liquefaction in terms of soil type, density, and earthquake intensity and duration. A correlation proposed by Prof. Seed of the University of California, Berkeley is shown in Figure 3. The correlation shown in figure 3 is for saturated, clean sands with less than 10% of dry weight of fines passing No 200 sieve. M on the curve designates Richter magnitude of design earthquake.

In 1990, Budhu and his associates at State University of Buffalo studied the Liquefaction potential of soils in Manhattan and their conclusions can be briefly summarized below:

- Manhattan Island can be divided into three areas based on probability of Liquefaction:
  High >50%, Moderate 10-50%, Low <10%
- Approximately one half of the study area has a high to moderate probability of Liquefaction. The high risk areas are adjacent to the shores of the Harlem River, the East River, and the Hudson River.
- Specifically, the soils adjacent to the Harlem River would be highly susceptible to liquefaction.
- The area generally to the north-west of Second Avenue has a low probability of liquefaction and does not appear to have significant risk of ground failure.
- Many parts of the study area, especially those bordering water, are reclaimed land formed by in filling with assorted debris. These areas were not evaluated due to lack of data.
- Ward and Randall Island's were not included in this study.
- The analysis was performed with an assumed earthquake with a peak ground acceleration of 0.15 g.
- The report and related data is for information purposes and should not be used to analyze existing or proposed structures without performing site specific investigation.

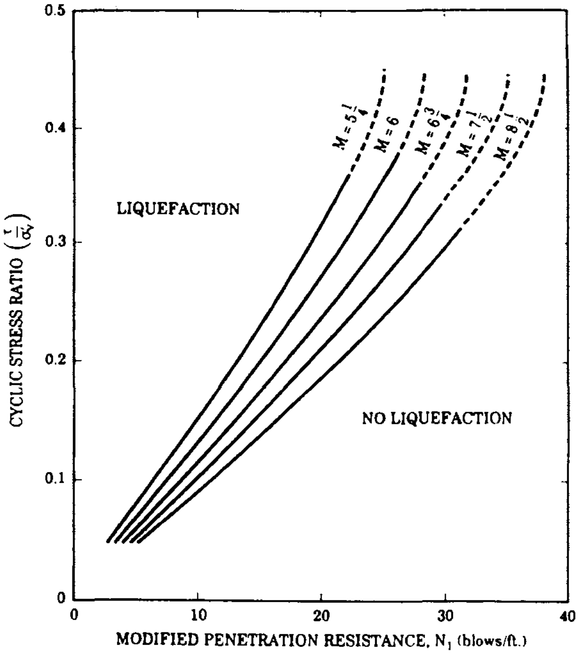

Fig. 3. Liquefaction Probability

Ground Motion and Response Spectra

It has long been recognized that the intensity of ground shaking during earthquakes and the associated damage to structures are greatly influenced by local geological and soil conditions. From a seismic point of view, the thickness and quality of soil overburden plays a significant role in controlling the primary frequency and acceleration level at the ground surface for a postulated seismic event. The seismic response of structure will be directly influenced by the properties of soil overburden. It has been observed that the sites which were approximately the same distance from the zone of energy release, experienced large variation in maximum ground acceleration presumably due to the different soil conditions underlying the recordings stations. Maximum ground acceleration does not alone determine the intensity of the shaking effects of a ground motion, these depend also on the frequency characteristics of the ground motion and its duration. The combined influence of the amplitude of ground accelerations, their frequency components and duration of the ground shaking on different structures is conventionally represented by means of a response spectrum which determines the lateral forces induced on engineering structure. The soil response spectra for different site conditions can be developed based on statistical and analytical procedures. Bureau of Bridges recommends to generate site specific spectra for critical and functionally important bridges and select an appropriate rock acceleration for seismic analysis satisfying the requirements AASHTO and NYSDOT guidelines. NYSDOT recommends a minimum rock acceleration value of 0.19g for all bridges.

Seismic Retrofit of Existing Bridges

By today's standards, most of existing bridges in this country have not been designed to resist earthquake forces. Therefore, many existing bridges may potentially be damaged or fail if subjected to strong seismic motions. To prevent earthquake related failure or to minimize the risk of unacceptable damage during an earthquake, seismic retrofitting of existing bridges is performed. Due to relatively large cost associated with strengthening of existing bridges to current design standards, the concept of retrofitting allows some degree of structural damage during an earthquake but prevents an unacceptable collapse of the structure. Published records seem to suggest that there are following four areas where severe damage to bridge structure may occur:

- Bearing, Support length and Expansion Joints
- Columns, Piers and footings
- Abutment
- Liquefaction of foundation soil

The extent of retrofitting to make bridges seismic resistant should be based on risk/cost analysis and importance of the bridge structure.

CURRENT SEISMIC STUDIES IN NYC DOT, BUREAU OF BRIDGES - DESIGN

EAST RIVER BRIDGES

1- Brooklyn Bridge
2- Manhattan Bridge
3- Williamsburg Bridge
4- Queensboro Bridge

HARLEM RIVER BRIDGES

5- Willis Avenue Bridge
6- 3rd Avenue Bridge
7- Madison Avenue Bridge
8- 145th Street Bridge
9- Macombs Dam Bridge

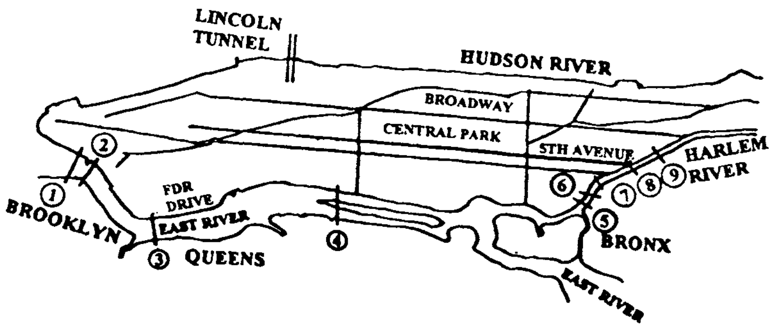

Fig. 4. Location of East River and Harlem River Bridges

In New York City, there are more than 75 bridges over waterways. Figure 4 highlights four major bridges over the East River and 6 bridges in the Harlem River which are focus of current and future seismic evaluation and retrofits respectively. The bridges over East River includes Brooklyn, Manhattan, Williamsburg and Queensboro bridges and were built before World War-I. Brooklyn, Manhattan and Williamsburg Bridges are suspended cable bridges with average main span of 450 meter and the average tower height is 100 meter. The Queensboro bridge is of steel truss with total length of structure about 2270 meter. Currently, seismic evaluation of East River bridges is in progress in the Bureau.

The bridges in Harlem River are primarily movable and lift span bridges commissioned in early twentieth century. Some of these bridges are designated Land Mark and present a special problem as the substructure is constructed of concrete filled stone masonry. The retrofit schemes will have to retain the Land Mark features and be acceptable to Art Commission. The Bureau will be initiating seismic evaluation of these critical bridges soon.

Summary

1. Recent revisions in AASHTO and NYSDOT guidelines require that existing and new bridges in New York City should satisfy seismic criteria. Therefore bridges in New York City are now designed and retrofitted meeting these seismic requirements.
2. Geology, seismic hazard and seismic geotechnical parameters pertaining to New York City were reviewed and has been discussed. The data presented here is of general nature and intended for information and preliminary evaluation. Bureau of Bridges recommends to perform site specific geotechnical study for critical and functionally important bridges.
3. For the design of bridges, attention should be given to the liquefaction potential of sub soils and their effects on foundation behavior. High risk areas appear to be adjacent to the shores of major waterways or rivers such as East River, Hudson River and Harlem River in Manhattan.
4. Seismic evaluation for Manhattan's East River Bridges and several other bridges in Brooklyn are in progress to come up with seismic retrofit scheme. Bureau will soon initiate seismic evaluation of several existing movable and lift span bridges over Harlem River in Manhattan.

ACKNOWLEDGMENTS

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REFERENCES

1. Standard Specifications for Highway Bridges; 15th Edition by American Association for Highway and Transportation Officials

2. Charles Scawthorn, Stephen K. Harris " Estimate of Earthquake Losses for a large Eastern U.S. Urban Center, Scenario Events for New York City" April 1988. Prepared for National Center for Earthquake Engineering Research (NCEER).

3. ASCE/ NYC Metropolitan Section Spring seminar 1993, "Designing Structures to Withstand Earthquakes"

4. Bulletin of Association of Engineering Geologists 1990 Vol XVII

5. Jain, S. K.; Kishore, K., "Geology and Selection of Optimum Foundation", US Department of Transportation, FHWA, International Conference on Design & Construction of Deep Foundation, December 1994.

6. Jain, S. K.; Kishore, K., " Geotechnical Aspects of Bridge Rehabilitation" , ASCE, ORVSS XXIV Soil Symposium, October 1993