Ground Motion Measurements from the Demolition of Steel Towers

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GROUND MOTION MEASUREMENTS FROM THE DEMOLITION OF STEEL TOWERS

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ABSTRACT

Steel towers from a decommissioned heavy water plant were to be demolished. Ground motions due to the proposed felling were estimated in order to assess the structural integrity of neighboring buildings and piping systems.

The extraction towers were 125 feet (38.1 m) high in two sizes: 6.5 and 11 feet (1.98 and 3.35 m) inside diameters weighing 215 X 10^3 and 470 X 10^3 lb (956 X 10^3 and 2.1 X 10^6 N). The total potential energy of the tower collapse was about 15 X 10^6 and 32 X 10^6 ft-lb (20.3 X 10^6 and 43.4 X 10^6 Nm) for the small and large towers, respectively.

The ground motion predictions were based on a credible theoretical relationship with constants estimated from data available for a different location at the site for dynamic compaction with an energy input an order of magnitude less than that for the towers. Due to the uncertainty of prediction of ground motions a coefficient of variation of 2.0 was used in the structural assessment.

Ground motion from the collapse of the extraction towers were monitored by several 3- and 6-components seismographs. Recorded measurements indicated that the ground motion was less than the predicted values. Peak radial motions were approximately equal to the vertical ones.

Video tapes of the demolition suggested significant internal energy losses. The measurements suggested that the tower potential energy conversion to dynamic impact energy was about 25 percent.

KEYWORDS

ground motion measurements, steel tower drops, tower collapse, predictions of ground motions, structural assessment of adjacent commodities, impact motion attenuation

INTRODUCTION

Steel towers from a decommissioned heavy water plant in D area at the Savannah River Site (SRS), South Carolina were to be demolished. The 125 feet high towers were to be felled in a cantilever mode, wherever possible. Felling of the towers was found to be more economical than removing piecemeal sections of the cylinder. Because of the potentially damaging levels of vibrations associated with the felling, assessment of the structural integrity of neighborhood commodities was required before the felling of the towers. The commodities included structural buildings, an above ground steam line, and buried piping within 50-200 feet of towers, shown in Fig.

1. Peak ground motion predictions were made by scaling peak motions observed from compaction weight drop tests conducted at SRS. The total potential energy of the towers were used to scale the weight drop ground motion data. Based on conservative tower ground motion predictions, it was assessed that the commodities would maintain their structural integrity.

Sensors were deployed to monitor ground motions for the first two tower drops, both typical of the 24 towers to eventually be felled. Observed ground motions and video of the felling suggest significant energy loss in the form of mechanical deformations and heat during the course of felling of the
towers. There was no noticeable structural damage for any adjacent commodities during these and subsequent tower drops.

This paper summarizes the method used for ground motion predictions, and compares the predictions with recorded observations during the tower drops.

Each Unit has 6 Towers

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**The Towers**

The extraction towers were 125 feet (38.1 m) high steel cylinders on top of 10 feet (3.05 m) high concrete pedestals. They had considerable decking on the inside, about 40 percent of the total weight making for the cylinder weight. The towers were fairly rigid due to the cylinder plate thickness and the internal decking. They came in two sizes: 6.5 and 11 feet (1.98 and 3.35 m) inside diameters weighing 215 X 10^3 lb (956 X 10^3 N) and 470 X 10^3 lb (2.1 X 10^6 N), respectively. One half of the total 48 extraction towers were not dropped as cantilevers due to potential environmental concern arising out of asbestos insulation. Among the dropped extraction towers 16 were small ones and the remaining 3 were large.

In addition there was one flare tower. It was an esthetically pleasing space frame 375 feet (114.3 m) high weighing 200 X 10^3 lb (890 X 10^3 N), 50 feet (15.2 m) square at the base and 6 feet (1.83 m) square at the top. The total potential energy for this tower was about 34 X 10^6 ft-lb (46.1 X 10^6 Nm). No measurements for the collapse of this tower were made because higher energy dissipation was expected and predicted motions were low relative to the location of commodities. Furthermore increased confidence was achieved through measurements of the extraction towers which were dropped first.

**Ground Motion Predictions**

Ideally, tower collapse ground motion predictions would use data recorded from structural type collapse impact on soils similar those found at D area. We were not aware of the existence of such data at the SRS nor for similar tower collapse on deep soils. As an alternative, weight impact data collected from soil compaction experiments were scaled to model the point energy sources.

**Dynamic Compaction Facility**

Sources of peak ground motion measured from dynamic compaction experiments at the SRS came from data reported by McMullin and Dendler [1994] based on measurements at the Dynamic Compaction Facility (DCF). Calibration tests were conducted by weight drops on virgin soil. The weights of 42 X 10^3 lb (187 X 10^3 N) were dropped from 50 feet (15.2 m); however, crane limitations reduced the free field energies by about 38 percent. Impact energies were determined by measuring the weight speed prior to impact. Forty-three sensors were deployed to measure ground velocity in three components. Peak particle velocity (PPV) was computed at each station as was estimated peak ground acceleration (PGA) and peak ground displacement. PPV versus distance recorded on virgin soil at the DCF is the basis for the ground motion predictions.

The variability of PPV with distance on natural soils at the DCF is shown in Fig. 2. A review of the recordings indicates that vertical and radial peak ground velocity values are about the same and much larger than the transverse component.

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**Fig. 2 DCF Upper and Lower Bound Peak Amplitudes**
Radial Attenuation

Peak component velocity bounds vs. distance were compared to some power-law attenuation relationships. Three attenuation models are illustrated in Fig. 3 with $1/R$ to powers of 1.0, 1.3, and 2.0. The $1/R$ scaling is a good approximation to the lower bound and is the proper theoretical scaling for point source seismic waves in the far field. The upper bound is well approximated by $1/R^{1.3}$ and may account for near source terms that attenuate at a higher rate. For the D Tower prediction we assumed that $1/R^{1.3}$ applies to the tower collapse based on the assumption of similar soils and structure between D area and the DCF. Depending on how the towers collapse, it is possible that the collapse may be best represented by a sum of nearly coincident vertical point sources along the collapse line. If so, the energy from this finite line source will attenuate at a slower rate than from a point source assumed in this paper. Because the towers are rigid and would collapse in a cantilever fashion from a 10 feet high concrete pedestal, the point source approximation is probably most appropriate.

Using the scaling factors derived above together with the radial attenuation shown in Fig. 3, the peak component velocity predictions for the extraction towers were made, Fig. 4. To employ these relationships for the towers, we assumed equalities of the peak vertical and radial components and

assumed the transverse component to be about 50% of the vertical component. The predominant frequency band for the velocity appeared to be generally in the range of 15-25 Hz.

Fig. 3 Models for Attenuation of Peak Component Velocity

The average DCF energy source was $1.3 \times 10^8$ lb-ft (1.76 $\times 10^8$ Nm), calculated for an efficiency of 62% for the weight drop. For energy scaling to D towers, we assumed that the peak particle velocity scales as the square root of the applied energy. The total potential energy for the small and large extraction towers was $15 \times 10^6$ and $32 \times 10^6$ ft-lb ($20.3 \times 10^6$ and $43.4 \times 10^6$ Nm), respectively. For prediction purposes the kinetic energy was taken at a point source and equal to the total potential energy. This suggests the scaling factors of 3.4 and 5.0 for the small and large extraction towers, respectively, with respect to the DCF energy source.

Predicted Peak Component Velocity

Using the scaling factors derived above together with the radial attenuation shown in Fig. 3, the peak component velocity predictions for the extraction towers were made, Fig. 4. To employ these relationships for the towers, we assumed equalities of the peak vertical and radial components and

Fig. 4 Predicted Peak Component Velocity

Fig. 5 Locations Plan for Measurement Instruments

MEASUREMENTS

Ground motions from the felling of the two extraction towers were recorded for the purposes of validating and calibrating prediction equations. The locations of the instruments are shown in Fig. 5. Commodity was evaluated based on the predicted peak ground motion and were judged to be adequate for the motions close to the towers.

Fig. 5 Locations Plan for Measurement Instruments
Instruments were deployed for the felling of the first small (6 feet diameter) extraction tower, Tower 1, then redeployed for the first large (11 feet diameter) tower, Tower 2. Three types of seismic instruments, normally employed for passive earthquake recording, were deployed for the demolition:

1. Kinemetrics SSA-1, digitally recording 3-components of acceleration
2. Kinemetrics SSR, digitally recording 2x3-components of acceleration
3. Teledyne PDAS, digitally recording 3-components of velocity

The PDAS machines used sensitive ‘S-13’ velocity transducers. The sensors were too sensitive for the measurements and were off scale at distances of 500 feet and consequently did not produce useful data. This situation still allowed redundancy in the recording of the important near source motions. Typical measurements from the felling of Tower 1 are shown in Fig. 6.

The values of the measured peak accelerations by orthogonal component and tower number are given in Table 1. As expected, the largest and approximately equal motions were measured in the radial and vertical directions with respect to the source. Two instruments, at 60 feet distance for Tower 1 and 87 feet distance for Tower 2, were deployed on the thick concrete pedestal supporting the towers. The foundations would act to reduce the high frequency motions and this was observed for the two instrument readings by comparison to the ‘free field’ motions.

**Table 1**

<table>
<thead>
<tr>
<th>Tower</th>
<th>R (ft)</th>
<th>Component</th>
<th>PGA (g’s)</th>
<th>PGV (in/sec)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>1</td>
<td>0.017</td>
<td>0.11</td>
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<td></td>
<td></td>
<td>2</td>
<td>0.090</td>
<td>0.73</td>
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<td>3</td>
<td>0.091</td>
<td>0.46</td>
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<tr>
<td></td>
<td>3</td>
<td>0.036</td>
<td>0.23</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
(a) Approximate radial distance measured from impact center to point of measurement.
(b) Component 1 is along plant NS; component 2 is vertical; and component 3 is along plant EW.
(c) Ground velocity obtained by integration of accelerogram and using half the peak-to-peak values.
(d) Foundation measurement.

The values in Table 1 were used to calibrate the prediction equation, which was based on virgin soil measurements. Reasonable agreement was achieved by using 1/4 the total potential energy of the towers. This energy reduction corresponds to a factor of 1/2 decrease in the predicted motions.

In addition to the ground motion monitoring program, there was a 2 minute video recording made of the two tower drops. Following the removal of the most of the tower support pedestals, the video illustrates how the tower was “pulled-down” using cables. The video also illustrates that the remaining tower supports absorbed significant energy before the tower began to fall.

**Comparison of Observations with Predictions**

The values in Table 1 suggested that only 1/4 of the total potential energy of the towers went to the soil as the kinetic energy at impact. That is, when the predicted velocities and accelerations were reduced by a factor of 0.5 there was a reasonable agreement between the recorded and predicted ground motion parameters.
A comparison of the predicted and observed peak component velocity as a function of the distance is given in Fig. 7.

![Graph showing comparison of predicted and observed velocities](image)

Fig. 7 Comparison of Predicted and Observed Velocities

The factor of 1/4 for conversion of total potential energy to dynamic impact energy is significantly low considering that the extraction tower structure was quite rigid.

EFFECTS ON ADJACENT BUILDINGS AND OTHER COMMODITIES

Based on the ground motion predictions it was assessed that the commodities shown in Fig. 1, namely the above ground steam line and buried piping systems, at least 100 feet (30.5 m) away, would maintain their structural integrity for the potential tower impacts. Buildings at least 100 feet (30.5 m) away were assessed to maintain structural integrity for the best estimate ground motion but likely to experience damage up to a distance of about 175 feet (53.3 m) for the best estimate plus one sigma value of 2.0 for the ground motion.

There was no noticeable structural damage for any commodities observed during drops of the 24 extraction towers and the flare tower.

CONCLUSIONS

The observations relating to the felling of the extraction towers in D area at SRS lead to the following conclusions:

1. A database correlating structural collapse type impact on deep soils and peak ground motion, which useful to the engineering community, was developed.
2. Vertical and radial peak components of ground motion are equal and much larger than the transverse.
3. Only about 1/4 of the total potential energy of the towers appears to have gone as the ground impact energy.
4. Predictions based on data available for a different location at the site for dynamic compaction with an energy input an order of magnitude less than that for the towers, and using 1/4 energy input for ground impact, matched reasonably well with the recorded measurements for one small and one large extraction tower.