Simulation of Near-Fault Ground Motions With Equivalent Pulses & Compare Their Effects on MRF Structures

Javad Vaseghi Amiri\textsuperscript{1}, M.R. Davoodi\textsuperscript{2} and Aliasghar Sahafi\textsuperscript{3}

\textsuperscript{1} Associate Professor of Noshirvani University of Technology, Babol, Iran.
\textsuperscript{2} Assistance Professor of Noshirvani University of Technology, Babol, Iran.
\textsuperscript{3} M.S.C student of Noshirvani University of Technology, Babol, Iran.
Email: vaseghi@nit.ac.ir

ABSTRACT

According to the recent earthquakes Near-Fault ground motions in the vicinity of quake field caused many damages. There is evidence indicating that ground shaking near a fault rupture may be characterized by an impulsive motion that exposes structures to high input energy at the beginning of the record. This pulse-type motion is particular to the forward direction, where the fault rupture propagates toward the site at a velocity close to the shear wave velocity, causing most of the seismic energy to arrive at the site within a short time. Near-fault Earthquake (NFE) come in large variations and this variety complicates evaluation or prediction of structural response unless they can be represented by a small number of simplified motions that can reasonably replicate important Near-Fault response characteristics. In this study, three pulse type models (which proposed by Makris & Agrawal previously) is used to simulate the Near-Fault records and their effect of this simulated motions on structures are compared to the actual NFE ones. For this reason, Four Near-Fault records are selected and we conduct this research by doing time history analysis & selecting 5,8 &12 stories steel buildings designed according to IRAN 2800 code. The results show that, with limitations, Near-Fault records can be represented by equivalent pulses to understand structural response but applying this result to design process is not recommended.

KEYWORDS:

Near-Fault Earthquakes, IRAN 2800 code, Pulse-type motions, Simulated motions, Simplified equivalent pulses, Time history analysis.
1. INTRODUCTION

An inspection of the time history records (especially velocity and displacement) of Near-Fault ground motions reveals their impulsive characteristics. Near-Fault ground motions come in large variations, which make a consistent evaluation of Near-Fault effects difficult and cumbersome. If simple pulse models can be found that represent Near-Fault ground motions with reasonable accuracy, the process of design or response evaluation will be significantly facilitated.

The study of similarities between the response of structures subjected to Near-Fault records and simple pulses provides much evidence that, help us to know better about this phenomenon and its effect on the response of the structures located in the near source zones. The study of the dynamic response of structures to impulsive loading dates back to the mid 20th century, when input pulses were first utilized to model the impact forces imposed by bomb blast. Biggs (1964) evaluated the response of elastic & inelastic SDOF systems to one-sided force pulses of various shapes, i.e., rectangular and ramp-like pulses. He observed that for each pulse shape, the maximum elastic response is a function of the pulse intensity and td/T ratio, where td is the duration of the pulse and T is the natural period of the system. Simple pulse shapes have been used in the literature also to represent earthquake ground motions (Veletsos et al., 1965). The response of elastic SDOF systems to a half-cycle sinusoidal force pulse is discussed in Chopra (1995).

Chopra demonstrated that the effect of damping on the maximum response to pulse-type forces is not significant unless the system is highly damped. Makris and Black introduced two pulse type models (Type A, B) to show pulse-like essence of Near-fault earthquakes. In Agrawal’s article (2002) a simplified closed-form approximation using decaying sinusoids is proposed to model long period velocity pulses in Near-fault ground motions. The objective of his formulation is to represent dominant kinematic characteristics of ground motions instead of modeling ground motions accurately.

The validity and usefulness of the proposed approximation is demonstrated using Near-Fault earthquakes measured during Northridge(1994) and landers (1992) earthquakes. Researchers introduced remoteness & nearness to the earthquake resource as the defining indicator of Near-Source waves. Alavi & Krawinkler defined the Near-Source phenomenon for the structures which are located at 10-15 Km from earthquake resource. Douglas & Ambraseys chose 15Km distance from fault but Chopra & Chintanapakdee considered the registered records up to 10 Km from earthquake resource as the Near-Fault ground motions.

2. EMPLOYED NEAR-FAULT RECORDS & SIMPLIFIED EQUIVALENT PULSE TYPE MODELS

4 Near-Fault records of the rest of the world are employed in this research. The registered records less than 15km are chosen as the Near-Source criterion. All records are provided from PEER internet site. According to ground type classification of IRAN 2800 code, which is divided into four zones, one Near-Source record is selected from each type, all the records scaled according to the IRAN 2800 Code which their specifications are represented in the Table 2.1.

In order to simulate the Near-Fault ground motions, three pulse type models which proposed by Makris & Agrawal is used. Makris proposed a one-sin acceleration pulse as a Type-A cyclical pulse which models the forward ground motion and a one-cosine acceleration pulse as a Type-B cyclical pulse that models a forward-and-backward motion. These pulses are given by the Eqs. 2.1 to 2.6. The pulse parameters are: \( V_p \), the amplitude of velocity pulse and is \( \omega_p = 2\pi/T_p \), the circular frequency of the pulse, which are selected judiciously to approximate the main displacement and velocity pulse.

**Pulse Type-A:**

\[
\ddot{u}_g(t) = \omega_p \frac{V_p}{2} \sin(\omega_p t) \quad ; \quad 0 \leq t \leq T_p
\]

\[
\dot{u}_g(t) = \frac{V_p}{2} - \frac{V_p}{2} \cos(\omega_p t) \quad ; \quad 0 \leq t \leq T_p
\]

\[
u_g(t) = \frac{V_p}{2} t - \frac{V_p}{2\omega_p} \sin(\omega_p t) \quad ; \quad 0 \leq t \leq T_p
\]
Agrawal proposed a simple approach for modeling velocity pulses by using decaying (damped) sinusoidal pulses (Type D pulse). The model is for forward rupture directivity conditions, which produce a strong pulse in the fault-normal direction. The pulse parameters that have been modeled are the natural frequency ($\omega_p$), amplitude of velocity pulse ($v_p$), and damping factor of ground motion ($\xi_p$) which controls the shape and duration of the velocity pulse. The proposed decaying sinusoidal pulse can be modeled as type A pulse using a high value of $\xi_p$ and it can be modeled as type B pulse by assuming smaller value of $\xi_p$. In the proposed Type D pulse, the velocity component $\ddot{u}_g$ of the pulse is modeled by a decaying sinusoid as follows [1]:

$$\ddot{u}_g = v_p e^{-\xi_p \omega_p t} \sin \left( \omega_p \sqrt{1 - \xi_p^2} \right). \quad (2.7)$$

Where $\xi_p$ is the damping factor of the decaying sinusoid, $\omega_p$ is the frequency of sinusoid and $v_p$ is the initial amplitude of the pulse. Differentiating Eqn. 2.7, the acceleration $\ddot{u}_g$ of the pulse obtained as:

$$\ddot{u}_g = v_p e^{\omega_p t} \left[ a \sin (bt) + b \cos (bt) \right] \quad (2.8)$$

And the displacement $u_g$ of the pulse can be obtained by integrating Eqn. 2.7 as follows:

$$u_g = \left[ v_p e^{\omega_p t} \left( a \sin (bt) - b \cos (bt) \right) + v_p b \right] / \omega_p^2 \quad (2.9)$$

Where $a = -\xi_p, \omega_p; b = \omega_p \sqrt{1 - \xi_p^2}$

Recent studies have shown that the input energy of ground motion depends mainly on the peak ground velocity (PGV) and the seismic index $I_D$ representing the effective duration of the ground motion [e.g., Manfredi (2001)]. These 2 parameters depend on $v_p$ and $\xi_p$ in the proposed approximation in Eqn. 2.7.
3. MATCHING OF NEAR-FAULT GROUND MOTIONS TO EQUIVALENT PULSES

In order to establish an equivalent pulse for a Near-Fault record, three parameters need to be evaluated; pulse type (A, B, or D), pulse period $T_p$, and pulse intensity. These three parameters completely characterize the equivalent pulse, and therefore its time history and response properties can be derived accordingly.

3.1 Procedure for matching

Mostly judgment is employed to decide on the pulse type, based on an inspection of the time history trace, and on a comparison between ground motion and pulse spectral shapes (primarily velocity spectra). In this study, according to the time history traces of the selected records, we use three pulse types A, B & D models to simulate the selected Near-Fault records. The pulse period ($T_p$) for a Near-Fault record is identified from the location of a global and clear peak in the velocity response spectrum. For records, in which the peak is not clear or there are two or more peaks, judgment has to be employed to decide on a final value of the $T_p$ [2]. Pulse intensity is chosen as the maximum of the time history velocity of the Near-Fault records and will be introduced as $V_p$. According to the pulse parameters definition for the pulse models, each record is equivalent by the parameters which come in Table 2.2. Figure 2 shows the simplified equivalent pulses of Type A, B & D for the H1 component of the Landers (1992) earthquake recorded at the 24Lucerne station.

4. ANALYSIS METHOD AND RESULTS

In this research, three MRF steel structures with 5, 8 & 12 stories are employed. These buildings are geometric regular and their typical story height & bays width are 3.20m & 3m, respectively (figure 1). The designed sections are considered as plate girder. In order to model the nonlinear response of structures trilinear behaviour model of SAP2000 software is employed in which FEMA273 code provides the hinges specifications .P-M-M hinges in columns & M hinges in beams are used. Damping factor of structure is proportional to the structure’s period ($\xi = 5\%$).

To compare the structural response to the records and their equivalent pulses, the distribution of the maximum story displacement & maximum story shear are selected in two directions (x, y) as the comparable response parameters. Using nonlinear time history analysis of SAP2000 software, structure’s response parameters under Near-Fault ground motions and their equivalent pulses are examined which the conclusions are expressed later. Analysis results for 5, 8 & 12 stories building are presented in coming pages.

5. CONCLUSION

Simple pulses of different shapes are utilized here to represent Near-Fault ground motions. This representation proves to be very efficient for an evaluation of imposed seismic demand to the structures. However, it is not
Figure 1 Plan & Elevation of employed buildings.

<table>
<thead>
<tr>
<th>Acceleration (g)</th>
<th>Velocity (Cm/s)</th>
<th>Displacement (Cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Record</td>
<td>Pulse Type-A</td>
<td>Pulse Type-B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pulse Type-D</td>
</tr>
</tbody>
</table>

Figure 2 Simplified Equivalent Pulses of Landers (1992) Earthquake
Figure 3 Max Story Shear Distribution (Actual records & Equivalent Pulse Type models)
Figure 4 Max Story Displacement Distribution (Actual records & Equivalent Pulse Type models)
reasonable to expect that perfect equivalence can be established between Near-fault ground motions and simple pulses for the full range of interest. The pulse representation of the Near-Fault earthquakes is not perfect but is believed to be helpful to have a better comprehension of the structural response to Near-Fault records. The following conclusions are drawn:

1) There are clear similarities between the response of frame structures to Near-Fault ground motions and the response to pulse-type excitations.
2) An inspection of the time history traces of the selected records and according to the analysis results, we can conclude that the pulse Type B,D models have a reasonable results in compare with pulse Type A model, i.e. the pulse Type B,D models can be used to simulate the selected records.
3) With the difference in the period of the structures, the nearness of the simplified equivalent pulses’ results and the actual records ones changes and will be closer.
4) The simplified equivalent pulses can capture the most important characteristics of the structure’s response which help us to have a better understanding of the Near-Fault ground motion’s effects on the frame structures.
5) The results show that, with limitations, Near-Fault records can be represented by equivalent pulses to understand structural response of the buildings but applying this result to design process is not recommended.
6) It is emphasized that the objective of the proposed approximation is to model dominant features of ground motions and should not be used to replace recorded ground motions to investigate structural behaviour.

REFERENCES:

2) Alavi Babak, Krawinkler Helmute;2001;Effects of Near-Fault ground motions on frame structures; The john A. Blume earthquake engineering center, Department of civil and environmental engineering Stanford University; Report NO.138(2001):1-301
5) Iran 2800 code of designing buildings against earthquake (ver. 3).
6) Iran national building rules,6th chapter, loading code (519).
8) Pacific Earthquake Engineering Research Center(PEER),”PEER Strong Motion Database”, Internet Website: http://peer.berkeley.edu