Research Objectives

The objective of this research is to further develop, apply, program, and disseminate the methodology for seismic risk analysis (SRA) of highway-roadway systems that was developed under FHWA-MCEER Project 106. The methodology’s risk-based framework uses models for seismology and geology, engineering (structural, geotechnical, and transportation), repair and reconstruction, system analysis, and economics to estimate systemwide direct losses and indirect losses due to reduced traffic flows and increased travel times caused by earthquake damage to the highway system. Results from this methodology also show how this damage can affect access to facilities critical to emergency response and recovery.

For the past several years, the Multidisciplinary Center for Earthquake Engineering Research has been carrying out highway research under the sponsorship of the Federal Highway Administration. One task from this research has developed a new methodology for deterministic and probabilistic seismic risk analysis (SRA) of highway systems nationwide, and has applied it to the Shelby County, Tennessee highway system (Werner et al., 2000). This methodology will enable users to evaluate and prioritize how various pre-earthquake seismic-risk-reduction strategies (e.g., strengthening of particular bridges, system enhancement) and post-earthquake emergency-response strategies (e.g., traffic management, emergency bypass road construction) will improve post-earthquake traffic flows and reduce associated losses.

During the past year, this SRA methodology has been independently validated (Eguchi et al., 2003), and a plan for developing the methodology into a public-domain software package named REDARS (Risks from Earthquake Damage to Roadway Systems) has been completed (Werner et al., 2003). This software will be programmed, beta-tested, applied to actual highway systems, and disseminated during the remainder of this research project.

However, before undertaking this effort, it was decided to first develop interim demonstration software (REDARS 1). This software, now completed, performs simplified deterministic SRA of the Los Angeles area high-
This SRA methodology will provide cost and risk information that will facilitate more rational evaluation of alternative seismic risk reduction strategies by decision makers from government and transportation agencies involved with improvement and upgrade of the highway-roadway infrastructure, emergency response planning, and transportation planning. Such strategies can include prioritization and seismic strengthening measures for existing bridges and other components, establishment of design criteria for new bridges and other components, construction of additional roadways to expand system redundancy, and post-earthquake traffic management planning.
Table 1. Technical Features of REDARS 1 and REDARS 2 (Werner et al., 2003)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Demo (REDARS 1)</th>
<th>Public Domain (REDARS 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Analysis</td>
<td>Deterministic</td>
<td>Deterministic and Probabilistic</td>
</tr>
<tr>
<td>Modularity</td>
<td>Not modular</td>
<td>Will be modular to facilitate adding new or updated seismic-hazard, component vulnerability, or repair/functionality models in future.</td>
</tr>
<tr>
<td>Seismic Hazards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground motions</td>
<td>From SHAKEMAP, for actual and hypothetical EQs in Los Angeles area.</td>
<td>Region-specific or imported models.</td>
</tr>
<tr>
<td>Others (liquefaction, surface fault rupture and landslide)</td>
<td>No</td>
<td>Liquefaction and surface fault rupture included. Landslide can be added in future.</td>
</tr>
<tr>
<td>Bridges</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New or retrofitted bridges</td>
<td>New only</td>
<td>New and retrofitted (when available)</td>
</tr>
<tr>
<td>Seismic hazards</td>
<td>Default model for ground shaking hazards only.</td>
<td>Default models for ground-shaking and ground deformation hazards (which can be overridden by separate user-specified fragility model for any bridge in network).</td>
</tr>
<tr>
<td>Repair/functionality models</td>
<td>First-order default model only.</td>
<td>Default model (which can be overridden with user-specified model that better reflects post-EQ repair resources in that particular region.</td>
</tr>
<tr>
<td>Other components (tunnels, pavements, embankments, walls, and culverts)</td>
<td>No</td>
<td>Tunnels and pavements to be included. Other components can be added in future.</td>
</tr>
<tr>
<td>Transportation network analysis</td>
<td>User Equilibrium (UE) method, with post-EQ trip demands assumed equal to pre-EQ demands.</td>
<td>UE method with fast numerical algorithms, and with congestion-dependent post-EQ trip demands not necessarily same as pre-EQ demands.</td>
</tr>
<tr>
<td>Economic Loss Estimates</td>
<td>First-order (based on travel time delays)</td>
<td>First-order (based on travel time delays)</td>
</tr>
<tr>
<td>Variance Reduction (statistical methods to reduce number of simulations needed to attain a given confidence level)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Input Data Wizard (to facilitate input data development)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Decision Guidance Post-Processor</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

ity is just east of downtown Los Angeles; and (d) the western extremity is the Pacific Ocean.

Earthquakes

REDARS 1 includes SHAKEMAP ground motion estimates within the above-indicated mapped area for: (a) actual earthquake events consisting of the San Fernando (1971), Whittier Narrows (1987), and Northridge (1994) earthquakes; and (b) hypothetical earthquakes estimated for rupture scenarios for the Newport-
Inglewood, the Raymond Fault, the 1857 event along the San Andreas Fault, the Santa Monica Fault, and the Whittier Fault.

**SRA Methodology**

The SRA methodology that is implemented in REDARS 1 is the deterministic element of the general deterministic and probabilistic approach described in Werner et al. (2000). For SHAKEMAP representations of ground motions in the above mapped area, REDARS 1 uses: (a) a rapid-pushover approach (Dutta and Mander, 1998; Mander and Basoz, 1999) to estimate median damage states for each bridge in the highway-roadway network; (b) a default model described in Werner et al. (2000) to estimate bridge traffic states as a function of bridge damage state, number of spans, and number of lanes; (c) a User Equilibrium algorithm to estimate traffic flows and travel times for each post-earthquake system state (Moore et al., 1997); and (d) the Caltrans (1994) model for estimating economic losses as a function of travel-time delay. The following paragraphs summarize these and other elements of the REDARS 1 SRA approach, together with additional features that will be included in REDARS 2.

**Ground Motion Uncertainties**

There are significant uncertainties in estimating ground motions throughout a spatially distributed highway system, and these uncertainties can have major effects on the estimated bridge damage and economic losses. Because REDARS 1 is deterministic, it cannot directly account for these uncertainties. However, as discussed later in this paper, REDARS 1 does enable the user to manually change the computed ground motions at any bridge site in order to facilitate limited sensitivity studies of the effects of ground motion variations on bridge- and highway-network performance. Of course, the probabilistic element of REDARS 2 will enable ground-motion uncertainties to be modeled directly.

**Bridge Damage-State Uncertainties**

As originally developed, the rapid-pushover method leads to bridge fragility curves that account for uncertainties in damage-state estimation. Because REDARS 1 is deterministic, it cannot directly account for these uncertainties; i.e., its SRA calculations consider only the 50th percentile damage state estimates from the rapid-pushover method. However, as noted later in this paper, REDARS 1 enables the user to manually change these damage states for any bridge. This will facilitate limited sensitivity studies of effects of damage-state uncertainties on highway-system performance, as well as limited evaluations of the effectiveness of various pre-earthquake seismic upgrade options or post-earthquake repair options. Of course, in contrast to this, the probabilistic element of REDARS 2 represents these uncertainties by directly using bridge-fragility models. (As noted later in this paper, these consist of rapid-pushover models as default curves which can be overridden for any bridge by more refined user-developed curves.)

**Bridge Modeling Simplifications**

The rapid-pushover method was developed to provide a simplified and rapid approach that uses avail-
able electronic bridge data in the current National Bridge Inventory (NBI) database (FHWA, 1995) for estimating damage to large number of bridges that would ordinarily need to be considered in SRA of a highway system. These simplifications (in which such factors as foundation and abutment response, effects of bridge retrofit, and bridge structural-system response are not included) could have important effects on bridge damage-state estimates.

Although more rigorous bridge damage-estimation procedures are available, their use in SRA applications methods will require additional structural-attribute data beyond that in the NBI database, and will also be more time-consuming to apply for large numbers of bridges. The use of improved damage-state estimation procedures, and development of electronic structural-attribute databases needed to apply these procedures, should be a focus of future research.

In recognition of this issue, REDARS 2 will enable users to input their own fragility curves for any bridge in the system. These curves would be developed beforehand, using whatever level of analytical rigor is deemed appropriate, and would then input these curves into REDARS by manually overriding the default fragility curves. Also, the modular structure of REDARS 2 will facilitate its accommodation of improved bridge-fragility models, as they are developed from future research programs.

**Bridge Functionality Model**

The model used in REDARS 1 for estimating bridge traffic-states as a function of bridge damage (and time after the earthquake) was originally developed to represent average default conditions throughout the United States. However, it is clear that the ability to implement repairs after a damaging earthquake will vary between different regions of the country, according to available repair resources and past experience in post-earthquake bridge repair. For example, the rapid recovery of the Los Angeles area highway system after the 1994 Northridge Earthquake was undoubtedly due in large part to lessons learned by Caltrans from past earthquakes, and also to their implementation of a bonus-incentive program to accelerate bridge repairs. Such factors are not considered in the REDARS 1 bridge traffic-state model.

In recognition of this issue, REDARS 2 will enable users to override these default models, and instead use their own traffic-state or functionality models that reflect user assessments of their repair experience/resources for the actual highway system being analyzed. This will also enable users to implement sensitivity studies of how changes in the repair process (e.g., deploying additional resources or a bonus-incentive program) can reduce potential losses due to highway-roadway system damage.

**Transportation Network Analysis Procedures**

Analysis of post-earthquake traffic flows in REDARS 1 is based on a User-Equilibrium (UE) model of transportation-system user behavior, which assumes that all users follow routes that minimize their travel times. In the application of this model in REDARS 1, it is assumed that post-earthquake trip
demands on the highway system are equal to pre-earthquake trip demands.

Past experience has shown that, following a major earthquake, the potential for increased congestion due to earthquake-induced roadway damage and closure can affect post-earthquake trip demands, causing them to be reduced (possibly substantially) relative to pre-earthquake demands. In recognition of this important issue, a new “variable-demand” approach has been developed for estimating post-earthquake trip demands as post-earthquake congestion (which, in turn, will depend on the extent of earthquake damage to the highway-roadway system.) This new model is now being tested, and will be included in the forthcoming REDARS 2 software.

As further discussed later in this paper, REDARS 1 includes an option to add equivalent “detour links”, in order to facilitate assessment of the effectiveness of various traffic management strategies in improving post-earthquake traffic flows and travel times. REDARS 2 will also include this option.

## REDARS 1 Implementation

### Opening of REDARS 1

REDARS 1 is opened by clicking on the REDARS icon on the user’s desktop or in his/her program file. When REDARS 1 is opened, the screen shown in Figure 1 is displayed.

### Selection of Scenario Earthquake

The user then selects the scenario earthquake to be analyzed by clicking on “File”, and then on “New” as shown in Figure 2. This displays the drop-down menu shown in Figure 2, which lists the various scenario earthquakes for which SRA of the
Los Angeles area highway system can be carried out by REDARS 1.

**Displays of Input Data Prior to Initiation of SRA**

When an earthquake scenario is selected, REDARS 1 displays the epicenter location as shown in Figure 3. Then, if it is desired to further examine various input data for the SRA, the user can click on “Map Views” in the toolbar for REDARS 1. This produces the drop-down menu shown in Figure 4, which shows that the user can display map views for the following input data: (a) NEHRP soil conditions at each bridge site (see Figures 5 and 6); (b) ground motions (spectral accelerations at periods of 0.3 sec. and 1.0 sec.) at each bridge site (see Figure 7); (c) the pre-earthquake roadway network; and (d) pre-earthquake traffic volumes. In this, Figures 5 and 6 show how legends can be added to these figures, by clicking on “”Map Legends” in the drop-down menu shown in Figure 5.

The user can also access tabular displays of input data for any bridge or link in the highway-system model by clicking on the “Select a Feature” button in the toolbar, and then clicking on the appropriate bridge or link (see Figure 6.) This feature is further described later in this paper.

**Computation of Bridge Damage States**

The next step in the application of REDARS 1 is to initiate calculation of damage states for all bridges in the system, when the bridges are
subjected to the SHAKEMAP ground motions for the selected scenario earthquake. This is accomplished by clicking on the “Calculate Bridge Damage States” button shown in Figure 7.

When these calculations are completed, REDARS 1 automatically provides the following displays for the existing (status-quo) bridges: (a) a map view showing each bridge’s damage state; and (b) a tabular summary of the damage-state results. These displays are shown in Figure 8. Figure 8 also shows that the list of map views and data tables that can now be accessed is expanded (relative to the earlier list shown in Figure 4) to also include bridge-damage information.

**Transportation Network-Analysis Computation**

After computing the bridge damage states, the user will initiate the calculation of the post-earthquake traffic flows and travel times by clicking on the “Evaluate Traffic Impacts” button as shown in Figure 8. As these calculations proceed, their status is continually displayed (Figure 9.)

When the calculations are completed, REDARS 1 automatically provides the following displays: (a) a map view of the bridge damage states and the roadway system state 7-days after the earthquake; and (b) a tabular summary of composite travel-times for the baseline (pre-earthquake) condition and at times
of 7-, 60-, and 150-days after the earthquake; and (c) the economic losses due to the differences between these pre- and post-earthquake travel-times. These displays are shown in Figure 10 for the status-quo highway system. Figure 10 also shows that the list of map views and data tables that can now be accessed is expanded (relative to the prior list shown in Figure 8) to now also include system-states, traffic-volumes, and access-egress times between origin-destination (O-D) zones throughout the region at times of 7-, 60-, and 150-days after the earthquake. Figures 11 and 12 show map views of traffic volumes and access-egress times respectively for the status-quo highway system at 7-days after the earthquake.

Modifications of Map Views

REDARS 1 enables the user to change the location and/or size of the area within the Los Angeles region for which the SRA input data and results are displayed. This is accomplished by clicking on the appropriate button in the REDARS 1 toolbar. Figure 13 shows that these buttons will enable the user to: (a) "pan" (translate the view); (b) enlarge or reduce the size of the area of the region included in the display — by selecting one of the various "zoom" buttons; (c) "identify a feature", which enables the user to select a particular bridge, roadway link, or O-D zone and display locations, attributes, and pre- and post-earthquake performance data; (d) refresh the view shown on the screen (if certain attributes have been manually changed by the user, 1 The composite system-wide travel time is equal to the sum of the travel times along all links in the REDARS model. It can be computed for the pre-earthquake (undamaged) system state, and then for various post-earthquake system states. Differences between composite travel times computed for the pre- and post-earthquake system states provide a first-order indication of overall effects of earthquake damage to the highway-roadway system, and can be used to estimate economic losses due to earthquake-induced travel-time delays (Werner et al., 2000).
as described below, and if new SRA calculations have been carried out for the given earthquake); (e) show the previous view or the next view; or (f) stop the display process.

**Tabular Display and Editing Features**

Figures 14 through 20 describe the steps involved in using REDARS 1 to display and edit SRA results for selected bridges, roadway links, and O-D zones. These features, many of which will be retained in the forthcoming REDARS 2 software, facilitate the use of SRA for guiding seismic-risk-reduction and emergency-response/recovery decisions for highway systems.

**Bridges**

Figure 14 shows how attribute data for any bridge can be displayed from a map view of bridge damage states. This display is accessed by: (a) clicking on the “select a feature” button in the toolbar; and (b) clicking on the particular bridge in the map view for which data display is desired. This will display a table of bridge attributes and damage states, as shown on the left side of the map view in Figure 14. The elements shown in white background in the table (i.e., the bridge’s ground motions and damage state) can be edited by the user, as described below.

**Manual Modification of Bridge Damage State:** An important benefit of SRA and REDARS will be its usefulness in enabling transportation agencies to evaluate the viability of various emergency-response
options in near-real time after an actual earthquake (including the relative effectiveness of these options in reducing post-earthquake traffic congestion.) One such option will invariably be how to establish priorities/sequences for repair of damaged bridges, according to which of these repair sequences will best improve traffic flows. Another option could be how to establish traffic-management strategies for reducing post-earthquake traffic congestion. The following paragraphs describe features of REDARS that will enable it to support decisions pertaining to post-earthquake bridge-repair priorities. Features of REDARS that will facilitate post-earthquake traffic-management decisions are summarized later in this paper.

To support decisions pertaining to post-earthquake bridge repair sequences, all versions of the REDARS SRA software will be able to use bridge damage states that are input by the user (rather than only relying on computed damage-state using the bridge models included in the software.) In this way, users will be able to incorporate actual bridge damage-state data into REDARS, as these data are obtained from post-earthquake field-reconnaissance surveys. This would involve the following steps: (a) with this actual damage-state data included, use REDARS to estimate post-earthquake traffic flows and economic losses; (b) simulate repair of selected bridges in the system, by manually changing the damage state for these bridges to corre-
spond to an undamaged condition; (c) after these simulated repairs are included, use REDARS to re-compute post-earthquake traffic flows and economic losses; (d) compare post-earthquake traffic flows and economic losses from alternative bridge-repair sequences simulated in this way, and also make comparisons with results for the system prior to any post-earthquake repairs; and (e) use these comparisons (and also considering the relative repair-implementation costs) to select a preferred bridge-repair sequence to actually implement.

Figures 15 and 16 show the steps for using REDARS 1 in this way. These steps consist of selecting a particular bridge to be upgraded, displaying its attributes, and manually changing its damage state. To facilitate this process when several closely-spaced bridges are involved, the software displays a list of all bridges that happen to be very near a given bridge that is selected. Then, the attributes for each of these bridges are separately displayed by clicking on the bridge in the list. When the manual modifications of bridge damage states are completed, the user then carries out a new network analysis by clicking on the “recalc” button shown on the right side of Figure 15. This results in the new display of bridge damage states, network analysis results, and economic loss estimates that is shown in Figure 16. Then, new map views of post-earthquake system states, traffic volumes, and access-egress times can be displayed by
appropriate selections from the drop-down menu shown in Figure 10.

To illustrate this process, let us assume that the damaged bridges shown in Figure 15 (which correspond to bridges near the junction of the Santa Monica and San Diego Freeways in Los Angeles) represent actual bridge damage-state data provided by field-reconnaissance teams after an actual earthquake. Let us also assume that the responsible transportation agency (e.g., California Department of Transportation) wishes to evaluate whether to repair these particular bridges before or after implementing repairs of other damaged bridges. To guide this decision, the agency can compare REDARS estimates of economic losses from Figure 15 (prior to repairs of these bridges) vs. those from Figure 16 (after the repairs are in place.) This comparison shows that the economic losses due to earthquake effects on the highway-system traffic flows are reduced by about $51 million when the repairs are implemented. Assessment of the benefits of this repair strategy (i.e., the reduced economic losses) in conjunction with the costs to actually implement the strategy can serve as a basis for deciding whether the repair strategy is viable\(^2\). Then, this process can be repeated for other plausible bridge-repair sequences, and those sequences with the most favorable costs and benefits would be implemented first.

\(^2\) Overall economic loss due to increased traffic congestion after an earthquake is only one of many system-performance metrics that can be a basis for decision making. For example, another possible performance metric can be the ability of a given bridge-repair sequence to improve access to/from certain key locations in the region (e.g., key medical facilities, airports, etc.)
Manual Modification of Bridge’s Input Ground Motions: The above deterministic analysis process is appropriate for rapid application in near-real time after an actual earthquake, in order to guide emergency-response decisions. However, for other types of decisions pertaining to longer-term post-earthquake recovery or to pre-earthquake planning of seismic-risk-reduction programs, probabilistic SRA procedures are much more appropriate, because of their ability to consider effects of uncertainties in: (a) earthquake occurrence, magnitude, and location; (b) seismic-hazards estimation; and (c) estimation of the seismic performance of the highway-system components (e.g., bridges) as well as the overall system itself. Probabilistic SRA of the Shelby County, Tennessee highway system that considers effects of such uncertainties is described in prior reports and technical papers developed under this FHWA-MCEER project (e.g., Werner et al., 2000; Werner, 2001.)

Although REDARS 1 is a deterministic SRA software package, it nevertheless provides a way to consider effects of such uncertainties in a limited way. For example, in addition to guiding user assessments of alternative bridge-repair sequences after an actual earthquake, the ability of REDARS 1 to accommodate manual modifications of bridge damage states can enable a user to roughly assess the sensitivity of highway-system seismic-performance predictions to uncertainties in bridge-damage-state estimates.

Another highly uncertain parameter is the estimation of site-specific ground motions for a given bridge in the highway system. To enable users to carry out a limited assessment of how ground-motion uncertainties can affect SRA results, REDARS 1 can accommodate manual changes to the original computed ground motions (i.e., the ground spectral accelerations at periods of 0.3 sec. and/or 1.0 sec.) at any bridge site.

Figures 17 and 18 show the steps involved in manually changing a given bridge’s input ground motions, re-estimating the bridge’s damage state, and repeating the network analysis. In the example shown in these figures, the spectral ground acceleration at a period of 1.0 sec. that was applied to a particular bridge (Bridge No. 1487) was manually changed from 0.68 g (which is the estimate from the SHAKEMAP model) to 0.50 g. Such changes of input ground motions can be carried out for any number of bridges in the system. Figure 15 shows that when the input ground motions are changed for any bridge, the prior summary displays of bridge damage states, network-analysis results, and economic-loss estimates no longer appear on the screen.

When all desired ground-motion changes are made for the various bridges in the system, the user proceeds to re-compute the damage states by clicking on the “Calculate Damage States” button shown in the right side of Figure 17. As shown in Figure 16, this results in a new display of bridge damage states. In this example, the assumed change in ground motions for Bridge No. 1487 modified its estimated damage state from 5 (collapse) to 4 (extensive).

Following this, the user clicks on the “Evaluate Traffic Impacts” button shown on the right side of Fig-
Figure 18, in order to carry out a new network analysis for this new set of damage states. Then, as described earlier, the user can display new map views of post-earthquake system states, traffic volumes, and access-egress times. Comparisons of these results before and after the ground-motion changes are in place will provide users with a first-order deterministic indication of the sensitivity of the highway-system performance estimates to the variations in ground motion for this particular earthquake event.

**Highway-Roadway Network Links**

Figure 19 shows how the attribute data for any link in the system can be displayed from a map view of the system state at 7-, 60-, or 150-days after the earthquake. This display is accessed by simply: (a) clicking on the “select a feature” button in the toolbar; and (b) clicking on the particular link in the map view for which data display is desired. This will result in the display of a table of link attributes, as shown on the left side of the map view in Figure 19.

In this link-attribute table, the attributes with a white background — which correspond to “detour lanes” at 7-, 60-, and 150-days after the earthquake — can be manually changed by the user. These parameters, whose initial values are set at 0, are included in REDARS 1 to facilitate assessment of various post-earthquake traffic-management strategies that may be considered, such as: (a) changing of certain roadway links from two-way to one-way traffic; (b) eliminating parking alongside certain roadways, thereby effectively adding one lane each-way to accommodate traffic; and (c) construction of a temporary emer-
emergency detour road alongside a non-redundant roadway segment that has been severely damaged during an earthquake. All of these traffic-management strategies were implemented at various locations throughout the greater Los Angeles area after the 1994 Northridge earthquake (Werner, 1995).

Figure 19 shows that the addition of “detour lanes” to simulate any of the above traffic-management strategies is accomplished by simply inserting an appropriate number of such lanes into the link-attribute table. Then, REDARS 1 uses these changed values to internally compile new system states at 7-, 60-, and 150-days after the earthquake. Next, by clicking on the “re-calc” button beneath the summary display of traffic impacts and economic losses, the user enables REDARS 1 to rerun the network analysis, in order to compute new estimates of traffic flows, travel times, and economic losses. When these computations are completed, the user will be able to follow procedures described earlier in this paper in order to display map views for the now-revised system states, traffic volumes, and O-D zone access-egress times.

It is noted that this option in REDARS 1 can facilitate evaluation of alternative traffic-management strategies after an actual earthquake, in much the same way as described earlier in this paper for assessing alternative bridge-repair priorities/sequences. That is, after a given traffic-management strategy is simulated and analyzed in RE-
DARS 1, potential benefits of the strategy can be established by comparing appropriate system-performance metrics (e.g., reductions in economic losses, improved access to key emergency-response locations) before and after the traffic-management strategy is implemented.

**Origin-Destination Zones**

Another important benefit of the REDARS SRA software is its ability to estimate the extent to which travel times to and from key locations in a region (e.g., medical centers, airports, centers of commerce, government centers, etc.) could be impacted by earthquake damage to the highway-roadway system. Significant disruptions of such travel times could impact the affected region’s ability to respond to and recover from the earthquake.

REDARS 1 enables users to develop tabular displays of access- and egress-times at any of the above post-earthquake times; (b) clicking on the “select a feature” button in the toolbar from that map view; and (c) clicking on the centroid of the particular O-D zone in the map view for which access-time and egress-time results are desired.

**Concluding Comments**

Prior to our forthcoming development of the detailed public domain REDARS 2 software for deterministic and probabilistic SRA of highway systems, an interim and simplified deterministic demonstration version of the software has been programmed. This software (REDARS 1) will provide users with an introduction to basic SRA concepts and results, as well as an opportunity to provide timely feedback regarding desirable software features to include in REDARS 2. This paper summarizes the main features and steps for applying REDARS 1. It also summarizes and compares various analytical elements of REDARS 1 and REDARS 2, and provides examples of how certain SRA results can be used to guide emergency-response decision-making.
References


