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# Data and Simulation of Ground Motion for Reno, Nevada

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## SUMMARY

Ground motions from the $M_w$ = 4.4 Dec. 2, 2000, west-northwest of Truckee, California, were used in an initial test case. Data recorded by local network and strong motion instruments were simulated in the frequency band from 0.2 Hz to 0.6 Hz. Simulations were made by a fourth order, 3D staggered grid elastic finite-difference code. A 1D synthetic Green's function in a layered elastic solid was much simpler than either the data or the synthetics, demonstrating that 3D basin effects are significant. Ground motion amplitudes are greater within the basin than on rock sites. This is also reflected by the synthetic data, but more so by the 3D results.

## INTRODUCTION

The cities of Reno and Sparks, Nevada, are located in a fault-controlled basin that is about 13 km wide and 21 km long. The small basin size, and the growing Advanced National Seismic System (ANSS) network within it, makes this area a very attractive location for improving basin modeling techniques. Our objective is to ascertain if 3D basin effects are significant, and if our preliminary 3D seismic velocity model is better than 1D and 2D models. The long-range goal is to achieve the ability to anticipate ground motion from future earthquakes in this rapidly growing urban area, with sufficient realism for engineering application.

Ground motions from a recent earthquake $M_w$ = 4.4 Dec. 2, 2000 event located about 60 km west of Reno are used in an initial test case. Data were recorded by local network and strong motion instruments. 1D, 2D and 3D synthetic seismograms are computed for the event and compared to the real seismogram data. This comparison enables us to assess basin amplification and the adequacy of a community velocity model for the area.

## DATA

### Earthquake Data

The $M_w$ = 4.4 Dec. 2, 2000 Truckee event is located about 50 km from the Reno area basin (Figure 1). An event description is given in Table 1. Event time and location was taken from the Nevada Seismological Laboratory (NSL) catalog. Seismic moment and depth of the event were taken from the University on California, Berkeley (UCB) moment tensor solution. The moment tensor inversion analysis was considered to better constrain the depth of the event than the NSL routine solution.

Data from the event was recorded by local network and ANSS strong motion instruments. Locations of these instrument stations are shown in Figure 1. Ground motions recorded by these instruments are shown in Figure 2. Accelerations are greater in the basin than on basement.

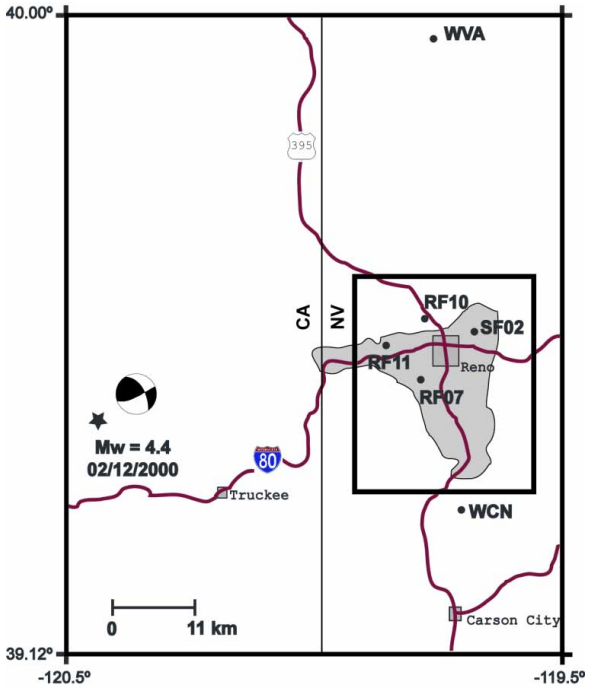


**Figure 1: Location of the $M_W$ = 4.4 2 December 2000 event. The UCB focal mechanism for the event is shown. Location of instruments which recorded the event are labeled. Gray shading highlights the boundaries of the Reno area basin. ANSS accelerometers = RF07, RF10, RF11, SF02. Network velocity sensors = WCN, WVA.**

Table 1: Description of the Truckee, CA event.

| | |
|---|---|
| Date | 2 December 2000 |
| Time | 1534 15.3670 |
| Location | 39.3787° N 120.4507° W |
| Depth | 11 km |
| $M_O$ | 5.17 E+22 Dyne-cm |
| $M_W$ | 4.4 |

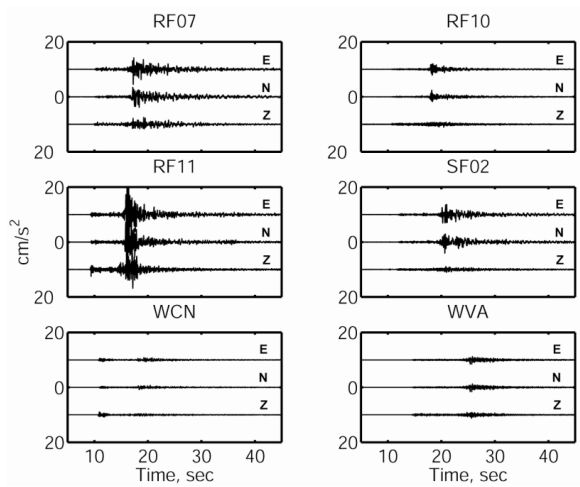


**Figure 2: Plot showing recorded ground motions of the $M_W$ = 4.4 2 December 2000 event.**

**Velocity Model**

We are constructing a three-dimensional seismic velocity model for the Reno area basin and surrounding region. The model specifies seismic velocities, density, and attenuation on a three dimensional grid. The seismic velocity model consists of local elements that, where available, supercede a regional velocity model. The regional velocity model, shown in Table 2, is the structure used for earthquake location in the area. Local elements are derived from the geological map (e.g. alluvium where the depth is proportional to distance from the nearest rock) or from detailed geophysical studies (e.g. Abbott & Louie [1]). Basin velocities are extrapolated based on borehole density measurements in Railroad Valley (Jachens & Moring [2]; Blakely *et al.* [3]) 400 km away in central Nevada. These density measurements are related to P wave velocity via Gardner's rule (Gardner *et al*. [3]). A Poisson solid is then assumed to extrapolate S velocities from P wave velocities.

The outline of the Reno Area basin is shown in Figure 1. Geometry and depth to bedrock within the Reno area basin (Abbott & Louie [4]) is shown in Figure 3.

Table 2: Background velocity structure used for the community velocity model.

| Depth, km | P Velocity, km/s | S Velocity, km/s | Density g/c$^3$ |
|---|---|---|---|
| 0.25 | 5.00 | 2.89 | 2.60 |
| 0.50 | 5.05 | 2.92 | 2.61 |
| 0.75 | 5.10 | 2.94 | 2.62 |
| 1.00 | 5.15 | 2.97 | 2.62 |
| 1.25 | 5.20 | 3.00 | 2.63 |
| 1.50 | 5.25 | 3.03 | 2.64 |
| 1.75 | 5.30 | 3.06 | 2.64 |
| 2.00 | 5.35 | 3.09 | 2.65 |
| 2.25 | 5.40 | 3.12 | 2.66 |
| 2.50 | 5.45 | 3.15 | 2.66 |
| 2.75 | 5.50 | 3.18 | 2.67 |
| 3.00 | 5.55 | 3.20 | 2.67 |
| 3.25 | 5.60 | 3.23 | 2.68 |
| 3.50 | 5.65 | 3.26 | 2.69 |
| 3.75 | 5.70 | 3.29 | 2.69 |
| 4.00 | 5.75 | 3.32 | 2.70 |
| 4.25 | 5.80 | 3.35 | 2.70 |
| 4.50 | 5.85 | 3.38 | 2.71 |
| 4.75 | 5.90 | 3.41 | 2.71 |
| 5.00 | 5.95 | 3.44 | 2.72 |
| 35.00 | 6.00 | 3.46 | 2.73 |
| 40.00 | 7.80 | 4.50 | 2.91 |

## SYNTHETIC MODELING

The seismic velocity model described above is implemented by the ground motion simulation codes. Simulations are made by a fourth order, 3D staggered grid elastic finite difference code (e3d: Larsen & Schultz [5]; Larsen & Grieger [6]), using a model area of 77 km by 99 km, down to a depth of 40 km. A Gaussian source time function with a rise time of 0.7s estimated from the corner frequency on the seismograms was applied. 1D synthetic Green's functions, computed in a layered elastic solid using the generalized reflection and transmission coefficients (Luco and Apsel [7]; Zeng & Anderson [8]), are also compared to both the real seismogram data and the e3d synthetics. The velocity model uses the same profile under the stations as the local profile used for the 3D simulations. Data and synthetics were band-

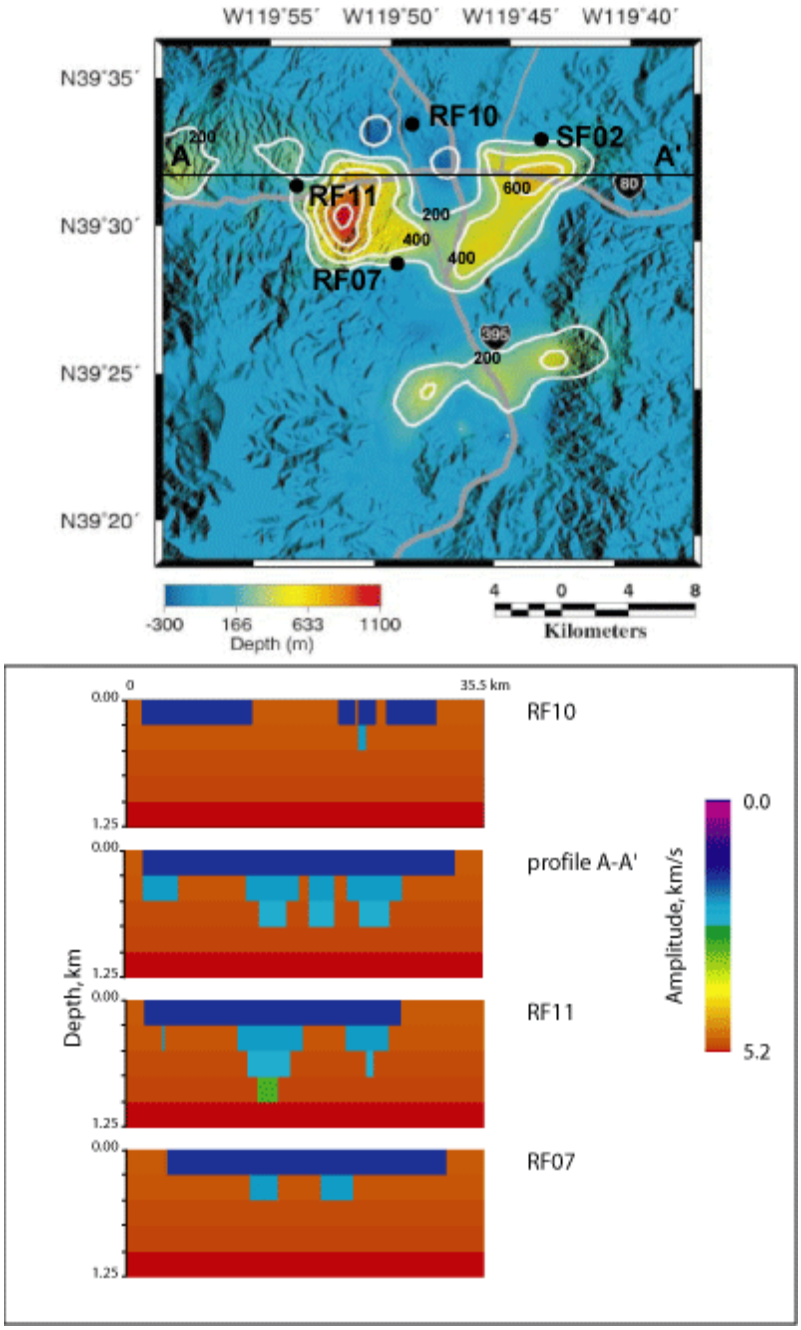


**Figure 3: Top: Contour map of basement depth within the Reno area basin. Bottom. East-west cross sections through the basin at the latitude of three of the ANSS accelerometer stations, plus an additional profile showing basin depth and velocity contours**

pass filtered with lower and upper filter corner frequencies of 0.2 Hz and 0.6 Hz, respectively. The lower limit is controlled by signal-to-noise ratios in the data, and the upper by the applicable range of the finite difference simulations.

## RESULTS

Comparison of the 1D, 2D and 3D synthetic seismograms are shown in Figure 4 for the east component at RF10. The 2D synthetics are limited in their application to ground motion simulation due to their line source, rather than point source, representation. The seismogram for the 2D simulation shown in Figure 4 has been transformed to a point source representation (Vidale *et al.* [9]). However, the 2D synthetic still differs from that of the 1D and 3D synthetics in waveform shape and amplitude due to the difference in source representation. The significant difference between the 2D and 3D waveforms demonstrate that 3D effects are important and thus we can conclude that 2D simulations are not adequate in this case. Figure 4 illustrates that 1D simulations do not replicate ground motion durations seen in the 2D and 3D synthetics.

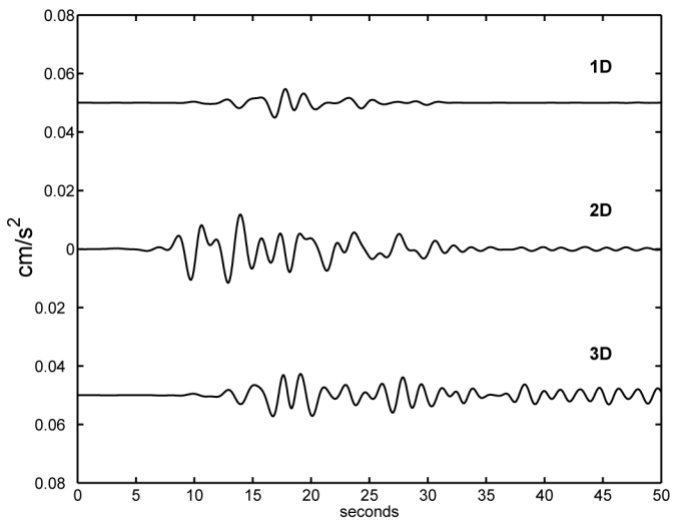


**Figure 4: Synthetic seismograms for the east component at RF10 (Figure 1). The 2D synthetic has been scaled by a half for comparison.**

Recorded data from all of the ANSS stations are compared with the 1D and 3D synthetics in Figure 5. The 3D finite difference synthetics match the durations of the data and may anticipate some of the later arrivals. The 1D code does not. Thus a 3D model that includes the Reno area basin is required to simulate ground motion within the Reno area basin. Ground motion amplitudes of the synthetics are greater within the basin than on rock sites.

Except for a few cases, the synthetic amplitudes are lower than those of the recorded data. This may indicate that the basin sediments of the community velocity model are too stiff. Further geophysical studies are required to improve our velocity model and hence our modeling capabilities. However, although not shown here, simulations for the network velocity sensors, which are located on bedrock, also show lower amplitudes than the data. This may suggest that the source strength estimated by the UCB moment tensor solution is too low or that there are velocity variations along the travel path from source to the recording sites that deviated from the background velocity model. The results might also be affected by focal mechanism.

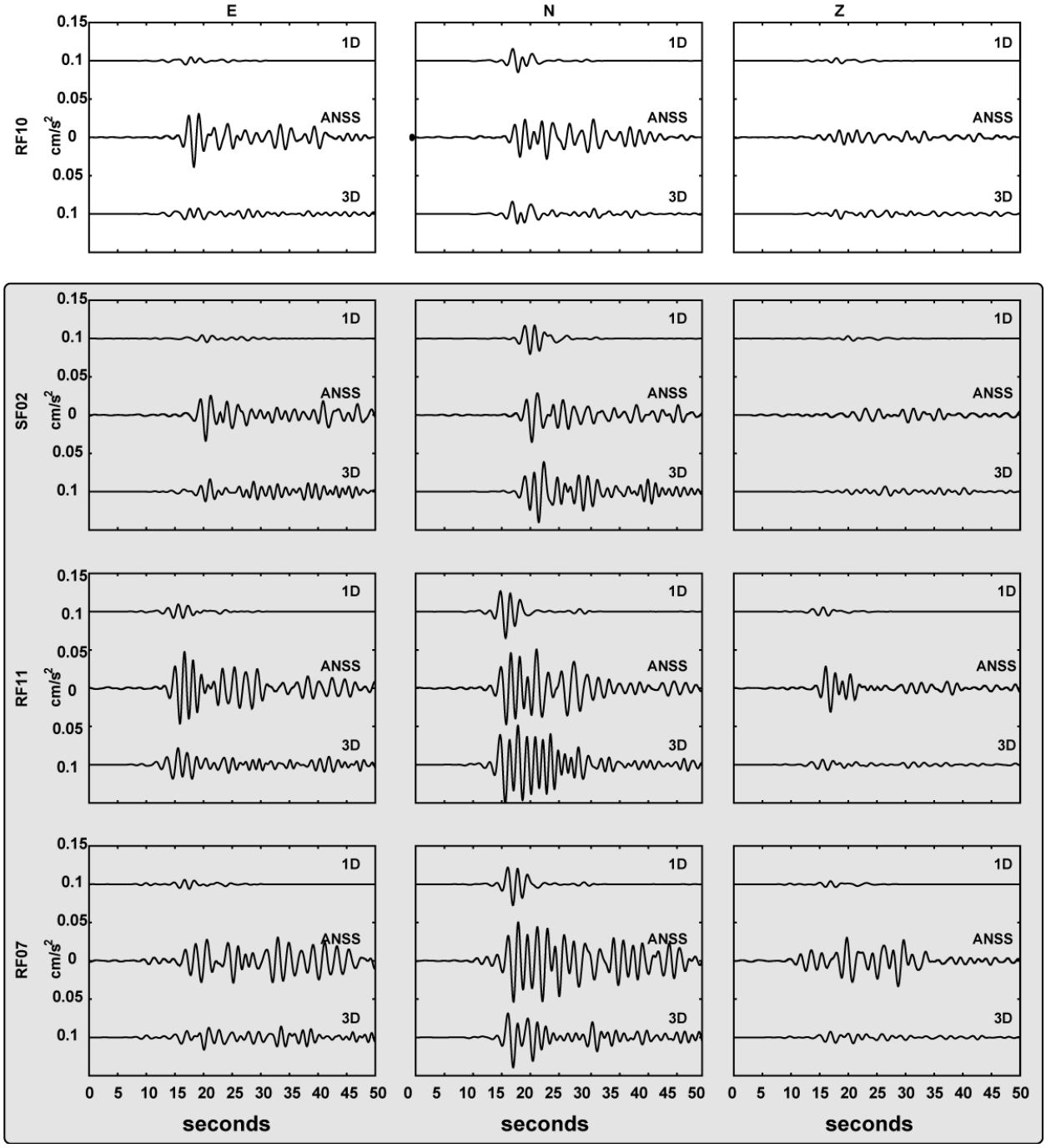


**Figure 5: Modeled ANSS seismograms: RF10 is located on bedrock. The gray background highlights stations within the basin, in order of increasing sediment depth. 1D and 3D synthetics are shown along with the ANSS data.**

Spectral ratios between the data recorded within the basin and data recorded at WCN is shown in Figure 6, as well as ratios between 3D synthetics at these stations and 3D synthetics at WCN. These ratios

normalize source effects. Normalization for distance attenuation proportional to $r^{-1}$ has also been applied, although this is a very small correction in this case (Figure 1). Ratios of recorded data at RF10 are near unity, as expected, for a rock site. Amplification is observed across a broad frequency range at all of the basin sites. Highest amplification is observed at RF11, which close to the deepest part of the Reno area basin.

Ratios for the 3D synthetics also show relatively low amplification at RF10. At basin stations, the vertical and east components of synthetics mostly have lower amplitudes and lower amplification than observed for this earthquake. Considerably more research is needed to refine the velocity model used to generate these synthetics before we will be able to come to a comprehensive explanation.

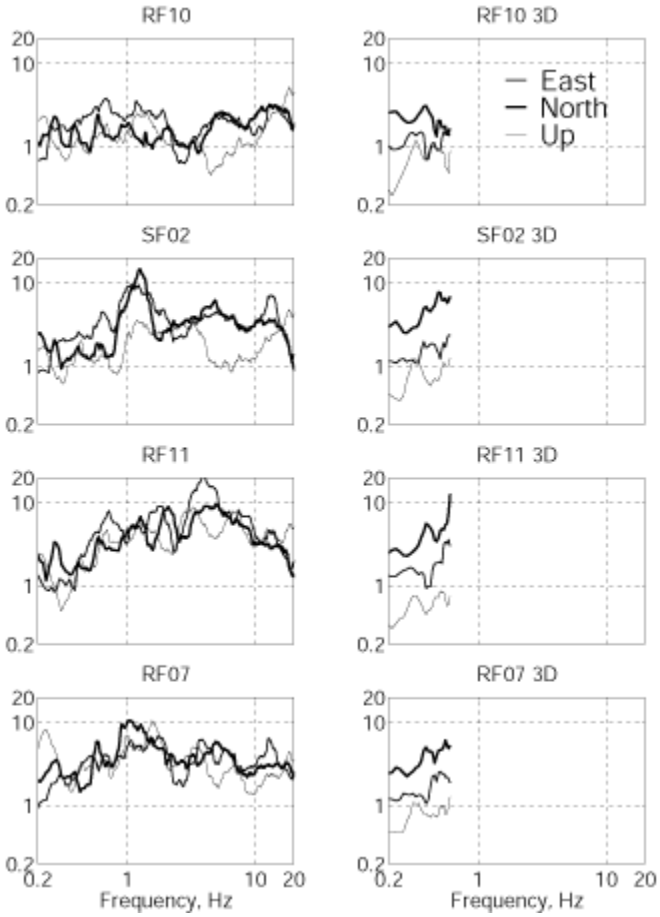


**Figure 6: Left: Plots showing spectral ratios of accelerometer data at RF07, RF10, RF11, and SR02 versus data from WCN. Right: Plots showing spectral ratios of 3D synthetics at RF07, RF10, RF11, and SR02 versus synthetics calculated at WCN. Source miss-calibration is eliminated by these ratios. Normalization for distance attenuation proportional to $r^{-1}$ has also been applied.**

## CONCLUSIONS

The most important conclusion in that these early results from the Advance National Seismic System network of accelerographs demonstrate significant basin amplification in the Reno area basin. Spectra are amplified over broad bands of frequencies by factors of 5 to 10 on the deepest basin sites. Future efforts will need to characterize these effects using data from more earthquakes, and more stations, to better inform future hazard analyses.

2D and 3D finite difference modeling matches the durations in the data and improves the amplitude prediction over 1D, while the 1D code does not. 3D models may anticipate some of the later arrivals. A 3D model is required to simulate ground motion within the Reno area basin, since 2D models are very different from 3D models, indicating that 3D effects are important. Discrepancies between the amplitudes of the data and the synthetics suggest that the preliminary community velocity model used to generate the synthetics needs to be refined.

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