June 12, 2015

MEMORANDUM

TO: SPEAKERS AND DISCUSSION PARTICIPANTS

FROM: GEORGE PRIEST, Tsunami Specialist, Oregon Department of Geology and Mineral Industries

SUBJECT: NOTES FROM THE MAY 18, 2015 WORKSHOP:
Designing for Tsunamis: New Oregon Data & Anticipated Changes to the Building Code

Thanks to all participants in the Oregon Department of Geology and Mineral Industries (DOGAMI)-sponsored workshop at the Portland State Office Building May 18, 2015. In my view we accomplished our principal objectives of gaining a better understanding of the evolving Chapter 6 of ASCE 7 on estimation of hydraulic forces for a 2,475-yr exceedance tsunami event and comparing how that event might match up to one of the published DOGAMI published tsunami simulations. All of us were impressed with the attention to detail and high quality of the draft ASCE building code presented by Gary Chock. This is a truly impressive product that will, without doubt, save lives when implemented. All involved should be proud of their achievement.

Gary Chock (Martin & Chock, Inc.) gave two excellent talks on details of the ASCE-7 guidance, an overview and then details. He emphasized that the new Chapter6 of ASCE 7 started development in 2011 and will be agreed upon by ASCE by the end of June 2015; out for public comment September-October 2015 with final publication March 2016. The new guidelines set minimum design standards for new construction of critical and essential facilities in the 2,475-yr exceedance tsunami flood zone in 5 western states. He went over the differences between requirements for Category I, II, III, and IV facilities with emphasis on vertical evacuation structures to be built where evacuation time is less than available time for evacuation and requiring functionality after the tsunami strikes. He pointed out that there are potentially many more informal vertical evacuation structures of opportunity in any given tsunami event. Gary mentioned that buildings higher than 4 stories (~65 ft) have base shear resistance large enough to resist most tsunami forces, so it may be important to allow some of these high rise structures where vertical evacuation is needed according to evacuation analyses, even if it means allowing variances from local zoning ordinances. For example, Seaside has a maximum commercial building height of 45 ft and Cannon Beach 32 ft, whereas tsunami flow depths can easily exceed those heights in low lying areas near the open coast (e.g. the projected 2,475-yr exceedance wave amplitude at 100m depth for these areas is on the order 35 ft).

In his second talk, Gary covered details of energy grade line (EGL) method for estimation of minimum tsunami forces that sets the “floor” for any detailed site-specific tsunami modeling of these forces, emphasizing that at least 3 transects to the inundation limit must be utilized and minimum velocity of 10fps assumed. There was some discussion about uncertainties of applying the EGL where there is no clear run-up limit such as at over washed sand spits, or, like in Seaside, over washed gravel bars bounded by shore-parallel wetlands or river channels. It was pointed out that tsunami velocities are generally at a maximum on the backside of over washed features, but the EGL does not apparently recognize this. Gary explained how the EGL is modified in this complex situation to set the “floor” for forces. It seemed clear that detailed simulation of the forces might be more critical in these complex situations. Gary then went on to explain how debris loads and impact forces from large ballistics were estimated. He emphasized that vertical evacuation facilities must be at least 1.3 x the 2,475-yr tsunami flow depth and not less than 1 story higher than the flow depth with effects from scour taken into account. Most impressive is that all of these detailed force calculations were consistent with actual field observations of the March 11, 2011 Tohoku tsunami and other empirical data.

Hong Kie Thio (AECOM) summarized the probabilistic tsunami hazard assessment (PTHA), explaining the way he handled for Cascadia the epistemic uncertainties (mainly alternative subduction zone fault slip models) and aleatory uncertainties from natural variability of the system (mainly such things as relatively unpredictable location of asperities). He explained that limiting the results to wave amplitude exceedance heights at 100m greatly simplifies the modeling because there is no need to simulate detailed coastal morphologies. His Cascadia fault rupture model used a 1x1 km grid based on the McCrory geometry for the subduction zone. He estimated slip and rupture area from global magnitude:slip and magnitude:area relationships, but also took into account some paleoseismic constraints on possible rupture lengths, all in accordance with the model used by the USGS for the 2014 update to the national seismic hazard maps. Variation of slip from concentrated slip in asperities was simulated by creating 3 asperities equal to 1/3 of each rupture length and simulating tsunamis from each of the 3 for every rupture scenario.

A series of simple unit subduction zone sources were used to estimate tsunami wave amplitude contributions of maximum-considered distant tsunami sources around the Pacific. Excellent graphics illustrated how disaggregation can resolve the relative contribution of each source to the hazard to the western US and Hawaii.

Yong Wei was given the task of estimating the 2,475 exceedance inundation from Hong Kie’s offshore wave height data – the guidance being that any tsunami scenario used must be within 80% of Hong’s amplitudes at 100m (less than 20% error). The resulting inundation zone establishes where the ASCE 7 regulations apply and where the run-up limit is for application of the EGL method. Yong also estimated coseismic subsidence, although no detail was given on how this was done. He mapped the inundation by creating simple unit sources for 8 north-south segments of the Cascadia margin and simulating inundation for each segment using a 2 arc second (60m) computational grid with a Manning Coefficient (friction) = 0.03; however, in some local areas there was already a NOAA forecast grid at a spacing of 10m that was also utilized. The Cascadia wave heights at 100m were approximated by creating tsunamis from unit fault sources using 24 100km-long x 50km-wide rectangular subfaults inclined to approximate the curving Cascadia subduction zone (12 north to south and 2 east to west). Slip was adjusted until resulting wave amplitudes matched within 20% of Hong’s heights at 100m water depth.

Discussion points from Yong’s talk:

- Typical slip for Aleutian unit sources was ~39-51m.
- Typical slip for Cascadia unit sources was 20-30m.

- Inundation was often overestimated where levees smaller than the grid resolution were present, but it may be justified since levees are not typically designed to resist tsunami currents.
- It is not trivial for unit sources to provide accurate estimates of both the coastal coseismic subsidence indicated by AECOM's 2,475-year subsidence map and the AECOM offshore tsunami amplitudes. The primary target of Yong's method is to provide accurate estimates of AECOM's offshore amplitudes. The principle of this method for coseismic subsidence is such that the reconstructed sources should produce coseismic subsidence on land so that the resultant change of land elevation is included in the inundation computation. It does not necessarily provide accurate estimates of the coseismic subsidence indicated by AECOM's subsidence map. In the EGL analysis, the amount of coseismic subsidence within the tsunami design zones will be directly indicated by AECOM's subsidence map (Note: the runup heights provided in Yong's TDZ maps are the land elevations at the inundation limit without coseismic subsidence, although it has been accounted for to compute the TDZ).
- George and Chris commented that the unit sources do not provide physically realistic estimates of the sources in Cascadia Subsuction Zone but are necessary in order create a 2,475-yr inundation zone within the available time and resources. The tsunamis from the unit sources appeared to, in one case (the coastline segment between 44.5N and 45.445N), be mainly from reflected waves or edge waves created north and south of the target inundation area which had a region of lower coseismic deformation immediately offshore. However, the domination of reflected or edge waves is not completely unrealistic because: (1) AECOM's offshore amplitudes are at 100 m depths, which are very close to shoreline and are affected by reflected or edge waves in reality. (2) In comparison with Yong's approach, AECOM's offshore tsunami amplitudes were produced using similar tsunami model and computational grids, and their estimates may have also included effects of reflected waves or edge waves.
- ASCE's future updates of the TDZ may explore the use of Hong Kie's sources for the Cascadia Subduction Zone. It is suggested that Oregon could participate in a refinement of the analysis that could become the basis for the ASCE 7-21 Standard and the local amendments of the Oregon Building Code 2019 or 2020 adopting the IBC 2018. There was a suggestion that perhaps one or more of Hong Kie's more realistic sources could be used to approximate the 100m wave amplitudes, eliminating physically unrealistic gaps and equally unrealistic coarse unit sources while providing much more defensible coseismic subsidence values. After the meeting, I suggested in e-mail that it should be possible for Hong to calculate 2,475-yr exceedance values for coseismic deformation at every one of his subfaults, thus providing probabilistic coseismic subsidence estimates for the coast. In subsequent review comments, Yong clarified that this estimate was already done for implementation of the EGL analysis, but apparently not used for estimated of coseismic subsidence for inundation simulations of the TDZ.
- The 60m resolution computational grid produced simulated inundation with apparent artifacts caused in part from missing smaller features but, from my review of some Oregon sites, possible errors in the underlying digital elevation model (DEM) may also be present. This issue is addressed by ASCE 7 guideline to use a complying 2,475-yr exceedance inundation based on a more refined grid, if available.

George Priest (DOGAMI)

The scientific basis for published DOGAMI tsunami simulation data was presented along with a listing of the publication products which include inundation maps, evacuation maps, selected time histories, and point data for every computational grid point (maximum velocities with vector component velocities for maxima, maximum momentum flux, maximum and minimum flow depths, maximum vorticities, and coseismic subsidence). The basis for all tsunami scenarios is deterministic rather than probabilistic, although the key basal branch of the logic tree determining the final logic tree weight (a reflection of relative confidence in each scenario) is estimated fraction of full-margin Cascadia ruptures over the last 10,000 years applicable to each "T-shirt" size category. No attempt was made to estimate the principal source of epistemic uncertainty from concentration of coseismic slip into asperities, varying slip along strike of the megathrust; instead all Cascadia sources were considered to have the full deterministic slip throughout the subduction zone. This simplification was justified by the observation that long, narrow sources like Cascadia radiate most tsunami energy perpendicular to the long axis. Observational constraints on tsunami size were principally the historical AD 1700 tsunami runup in Japan, extent of the last 3 Cascadia tsunamis deposits at Cannon Beach, and the 4600-yr record of tsunami deposits in Bradley Lake in southern Oregon. The Japanese data were best fit by a uniform, whole-margin rupture with 19m slip, the Cannon Beach inundation by a minimum of peak slip of 14-15m for, and Bradley Lake by at least 12-13m peak slip to breach the 6m barrier at the lake outlet. Cannon Beach is located where the turbidite-defined segments A and B overlap and Bradley Lake where segments A, B, and C overlap; the recurrence of the Bradley lake tsunami deposits approximates the recurrence of the segment A, B, and C turbidites directly offshore. The relative size of turbidites, a qualitative measure of earthquake size, indicated that AD 1700 was an "average" event and earthquakes that caused the mapped tsunami deposits at Cannon Beach were either average or relatively small events as well. None of the paleotsunami data set maxima on tsunami size, only minima. Maxima were constrained mainly by available slip on the subduction zone over the 10,000 yrs of turbidite observations, the total number of events, and inferred seismic gaps which, in northern Oregon and Washington approach ~1200 yrs within uncertainty of age data; thus 1200 yrs was inferred to be the slip deficit for a maximum-considered event; at typical plate convergence rates this translates to ~40m of slip, similar to maximum slip observed in the 1960 Chile and the 2011 Tohoku earthquakes. Turbidite mass data suggest that such maximum events have occurred ~1-2 times over the last 10,000 yrs, so recurrence is ~5000-10,000 years. This was a key point in later discussions.

The current regulatory framework for current State of Oregon restrictions on new construction of critical, essential, large occupancy, and hazardous facilities was briefly covered. Flow charts of showing how this works in the permitting process illustrated that in every case the local building codes official is the gatekeeper at the beginning of the process, interpreting whether the facility falls under the regulation. The implementing inundation zone was mapped in 1995 on USGS topographic maps and approximated what we now know was approximately an average Cascadia event. There was a 2014 recommendation by an advisory committee to replace the current zone with the "Large" or L1 tsunami inundation zone mapped on much more accurate lidar base maps, the recommendation heavily influenced by the approximation of L1 to a ~2500-yr exceedance event in the 2013 pilot study of

Crescent City by URS and UW. No DOGAMI Governing Board action has as yet been taken on this recommendation.

Discussion and questions on this talk were mainly regarding clarifications of technical points.

Joseph Zhang (Virginia Institute of Marine Science) presented comparisons of published DOGAMI deterministic scenarios to approximations of ASCE 7 scenario. The work is preliminary, because he mistakenly used zero friction instead of the ASCE 7 value, n=0.03 for the simulations of the ASCE 7 scenario on DOGAMI computational grids, so comparisons of DOGAMI hydraulic forces (momentum flux) to ASCE 7 were not really possible. There was also some confusion about how to calculate forces from the Energy Grade Line method that Gary Chock kindly offered to help him resolve. Nevertheless, these issues did not affect comparison of the DOGAMI "T-shirt" tsunami wave heights offshore at 100m depth to ASCE 2,145-yr exceedance heights from Hong Kie Thio. Three DOGAMI computational grids were picked representing the north, central and south coast: southern Clatsop County (Seaside area), central Lincoln County (Newport), and Coos County (Bandon area). It appears that none of the DOGAMI scenarios match ASCE, but the XXL1 or XL1 seem closest to on the in the north and south coast while the L1, or "Large" scenario matched was closest on the central coast. The preliminary calculations of hydraulic forces, even with some errors, were also consistent with the pattern of offshore wave height, as would be expected.

Discussion centered mainly on concern that use by the DOGAMI scenarios of zero friction would overestimate flow velocities and thus momentum flux, if any were used as proxies for an ASCE 7-compliant 2,475-yr exceedance event. Joseph will explore this issue further with the ASCE n=0.03 value for his simulations.

General Discussion

The general discussion centered mainly on ways of possibly improving the ASCE 7 approach to estimation of the 2,475-yr exceedance inundation zone and offshore wave heights for the Cascadia margin (Washington, Oregon, and northernmost California). Chris Goldfinger suggested that the work on the complex Cascadia subduction zone would have benefitted from a team approach with specialists in subduction zone fault mechanics, geology, and paleoseismology collaborating with tsunami modelers. Rick Wilson mentioned that the initial approach was vetted by such specialists, including most science participants at this meeting, as part of the California PTHA Work Group over a period of several years before and after the 2013 work was done. It was also stated that the recommendations of this Work Group were incorporated into the updated PTHA of the Cascadia SZ used for the ASCE 7 work. There was spirited debate about whether this produced any substantive modifications of the approach, in which Goldfinger and Priest argued that review was "inverted" that is, performed after any substantial changes could be made, but Hong Kie Thio's departure to catch a flight out prevented a comprehensive discussion. It is known that the 2013 logic tree was modified to better match the USGS seismic sources used for the national seismic hazard maps. The approximate match of Hong's 2013 2,475-exceedance inundation of Crescent City to the DOGAMI L1 inundation there versus approximate match of Hong's 2014 wave heights in southern Oregon to the XXL1 scenario supports an inference that the 2014 ASCE 7 scenario tsunami probably exceeds the 2013 scenario. Since the XXL1 source scenario required ~40m of coseismic slip and ~1200 yrs of slip deficit release on the Cascadia subduction zone, the question was asked whether this much slip could be released often enough to produce the 2,475-yr event, within geological constraints, particularly the 10,000-yr balance of slip to convergence. Gary Chock and others commented that addition of the epistemic uncertainty in the probabilistic analysis generally biases the result to larger (more conservative) values relative to what might come out of a deterministic approach like that used for the DOGAMI analysis. Since the principal source of aleatory variability for coseismic slip was handled by Hong by moving a model asperity along the subduction zone, basically doubling slip in the asperity, George Priest suggested that this was probably the reason that results were biased to high values. Hong Kie replied in his review of the meeting summary that this is not really the case. The asperity(s) is something we observe with every earthquake, and on average the maximum slip (in the asperity) is twice the average slip over the entire rupture. Using asperities is a way to include slip distribution variability. The larger offshore wave heights compared to the DOGAMI models may be the result of a combination of modeling error (sigma) which we include as well as scaling relations that predict larger magnitude versus length. The comment from Gary Chock and others was that this type of bias to higher values is consistent with engineering practice where lives are at stake. Chris Goldfinger, while agreeing with the underlying philosophy, noted that there should be bounds placed on such additive conservatism to prevent going well beyond what is physically possible. He also noted that it would potentially be easier for people to understand and accept if the conservatism were added after the wave generation, that is, to the downstream parameters needed to assess engineering requirements. Adding them up front to the wave heights produces outlandish waves that cannot be compared with any existing science.

After the meeting, Hong Kie Thio responded that he did not agree with the statement that the ASCE review process was inverted, and that the review committee's comments were ignored. Hong mentioned that many details about how his 2013 approach was modified in 2014 were not made available before or during the meeting and provided the following summary of how the process developed and how review comments were incorporated in the final ASCE 7 product (with some minor editing by me):

1. The curved and finer grid used in the new model was a direct response to the comments.
2. Recurrence model, which is now largely based on the 2014 USGS model that includes many of Chris's comments, and has been vetted through peer review. This was a direct consequence of the reviews we got, the previous model was more generic.
3. Slip distribution along the width of the rupture, follows more closely (not exactly) the "bell shaped" distribution used for the Oregon deterministic scenarios.
4. Smaller weight/stronger tapering to scenarios that break all the way to the trench.

Hong added that the process of adding variability to the modeling by amping up the offshore amplitudes may be not very intuitive, but is much more consistent with the process of how these variabilities manifest themselves or are determined. Because of the non-linear character of the inundation, it's very important to propagate these variabilities inland as much as we can. We do add another variability term to the final inundation as well, but that's just to account for the actual inundation errors, not the offshore amplitudes. This practice is also very consistent with the seismic methodology.

Gary Chock commented in his review of the meeting summary that the procedure by which the probabilistic Offshore Tsunami Amplitude is utilized in developing the TDZ (Tsunami Design Zone) is based on using one or more surrogate tsunami scenarios generated from the principal disaggregated seismic source regions that replicate the offshore tsunami waveform characteristics for the site of interest, taking into account the net effect of the probabilistic treatment of uncertainty into the offshore wave amplitude of the scenario(s). These are called Hazard-Consistent Tsunami as a term of craft within ASCE 7, referring to a means to replicate the effects of the Maximum Considered Tsunami (MCT) hazard level by a more limited number of surrogate scenarios. Hazard-Consistent Tsunamis are devised to incorporate the net effect of an explicit estimation of uncertainty in the parameters originally used in determining the MCT through conducting the probabilistic tsunami hazard analysis. This is a procedural device to produce a convenient representation of input for a more limited number of inundation analyses. By selecting the Hazard-Consistent Tsunami scenarios from the principal seismic sources that contribute to the hazard, where the offshore tsunami amplitude of the scenario matches the probabilistic offshore tsunami amplitude, one can calculate the hazard-consistent inundation. So, while a multitude of scenarios may be run to determine the probabilistic Offshore Tsunami Amplitude, a much smaller number of scenarios from the predominant sources can be run for the inundation limit and runup maps for a particular geographic region.

Gary also commented in his review of the summary that it should be recognized that any Hazard Consistent Tsunami will include upward scaling for both epistemic uncertainty and aleatory variation. Therefore, the statement that, as an example, "the XL scenario matches the ASCE 7 Offshore Tsunami Amplitude of 2500-year MRI" is not strictly correct. Actually, viewed in the probabilistic domain, the statement would be "some deterministic scenario less severe when implicitly scaled up to account for epistemic uncertainty and aleatory variability, has the appearance of similarity to the XL scenario." (You do not know what the "baseline" deterministic scenario is until you have estimated the epistemic uncertainty and aleatory variability of the modeling method used.)

Additionally, Gary noted that in general, it is not necessarily inconsistent that a Hazard Consistent Tsunami for one area would be different than that for another area. The hazard level is calculated to obtain the net probability of an offshore amplitude based on probabilistically determining the *non-exceedance* of that amplitude from all possible sources. That means that a source or a segment of a source that is not primary still mathematically influences the probability level of any amplitude of interest. In the deterministic world, one typically tries to find the "governing" dominant scenario and then discounts all others; that is never done in the seismic design maps or the wind design maps or the flood design maps used in the ASCE 7 Standard, and that is not done in developing the ASCE 7 tsunami design provisions.

The other main topic was ways of improving the estimation of the ASCE 7 Tsunami Design Zone from Hong Kie Thio's wave height data on the Cascadia margin. The main issue was finding a more scientifically satisfying way of simulating both the wave and the 2,475-yr exceedance coseismic subsidence. I suggested that one of Hong's Cascadia source models might provide a better fit to offshore wave heights at any given latitude than using physically unrealistic unit sources; the advantage being that Hong's sources also provide more realistic coseismic subsidence. After the meeting I suggested in e-mail that the 2,475-yr exceedance coastal subsidence could, in theory, be calculated from Hong's sources for any part of the coast. In subsequent review comments, Yong Wei clarified that this estimate was already done for implementation of the EGL analysis, but Hong Kie's sources were not directly used for estimate of coseismic subsidence for inundation simulations of the TDZ.

In a follow up e-mail I suggested that, if there is already a 2,475-yr exceedance subsidence estimate, then there should be a 2,475-yr exceedance value for vertical deformation for every computational grid point in Hong Kie Thio's Cascadia fault source model. My thought is that this vertical deformation might serve as a viable source for simulation of the 2475-yr inundation zone (TDZ) and would directly incorporate Hong's best estimate of coastal subsidence. It would be interesting to see if this source does indeed produce wave heights at 100m fitting the 80% match requirement. Hong Kie Thio responded in e-mail that this was an interesting suggestion, but that he needed to think about whether this could work. He said that "we have a 2475 exceedance subsidence grid, and we can create the same for uplift, but I am not sure we can create one that has both. Subsidence and uplift are, for the probabilistic purposes, different parameters." My response was that it might be possible to approach the problem by using fault slip as the exceedance parameter which would translate to 2475-yr exceedance for all vertical deformation. Hong Kie replied by e-mail as follows:
It's an intriguing solution if you want to have a single-scenario equivalent to represent the hazard, as we are trying to do for the ASCE project. I agree that it is desirable to match the uplift/subsidence maps but you'd still need to be able to match the offshore exceedance wave heights though. There's no guarantee that you will, I think. When I find the time, I will create an exceedance slip model just to try it out. The problem with all single-scenario approaches it that by trying to fit all offshore wave heights at the same time, we may be matching the largest wave (probably the direct wave) correctly, but there may be issues with smaller but still significant arrivals such as edge waves (since earthquakes generally have very heterogeneous, along-strike and dip, slip distributions).For the California maps, we are integrating over a much larger set of events that represent the range of epistemic and aleatory uncertainties/variabilities. It's much more expensive, and outside the scope of the ASCE effort.

What was lost in the general discussion of the Cascadia problem, which consumed all time at the end, was how impressed all participants were with the overall high quality of the ASCE 7 work by Gary Chock and the rest of the team. Their techniques for estimation of hydraulic forces are based on detailed field observations at Tohoku and other areas as well as high quality physical modeling and are without doubt the state of the art at the present time. There was also no argument that the approach for estimation of the probability of distant tsunamis was similarly of high quality. Given the limited time and budget for this work, the product really is extraordinary. Apologies to all participants that this point was not made at adjournment. I hope this summary will help make up for that omission.