Structural collapse risk estimation
&
Seismic design code calibration

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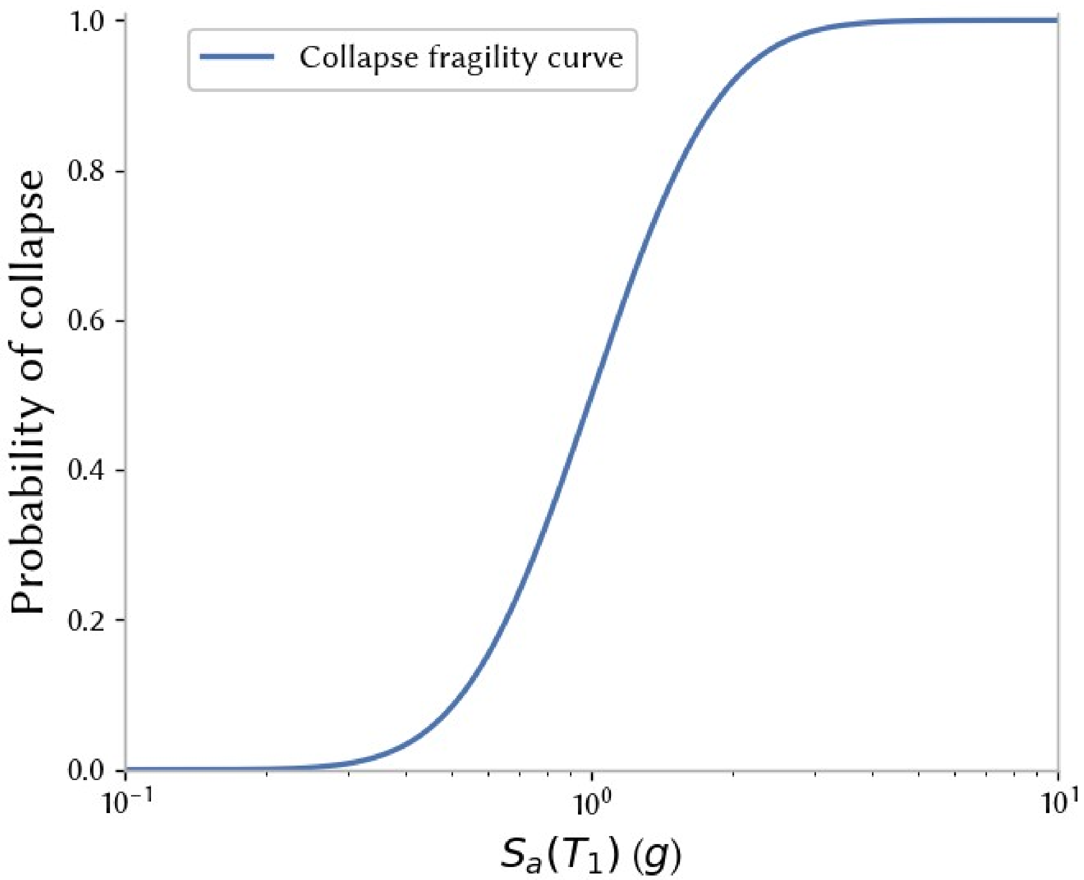
Objectives of seismic design

- Primary objective: To limit loss of life due to structural collapse
- Secondary objective: To limit monetary losses due to damage and downtime
- NZS 1170.5 targets an annual fatality probability of 10^{-6}
  - Annual structural collapse probability: 10^{-4} to 10^{-6}
  - Probability of fatality given collapse has occurred: 10^{-1} to 10^{-2}
- It is currently impractical to verify this objective for each new design via analysis
- But little to no research has been conducted to verify this performance objective for code-conforming buildings
- Some work has been done in the US during the development of the FEMA P695 guidelines, but there's plenty of scope for improvement
- Need to obtain our best estimate using our current modelling capabilities and fine-tune this estimate as our capabilities improve

Why is code-calibration important?

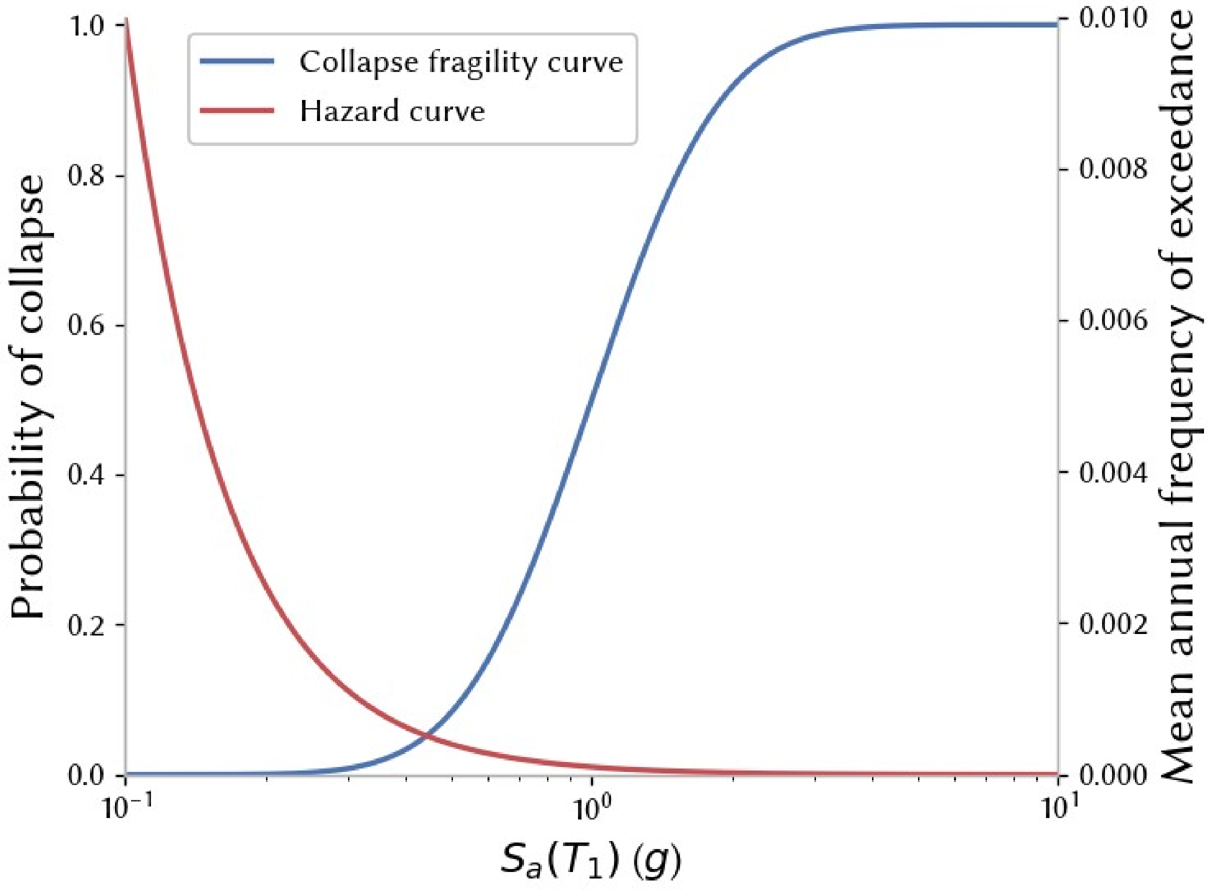
- Communicating expected building performance with public and stakeholders
- Quantifying the benefits of newly developed low-damage technology
- Developing a rational basis for some subjective design parameters such as the S_p factor
- Ensuring uniform distribution of seismic risk over different geographical regions and different structural systems

Structural collapse risk estimation



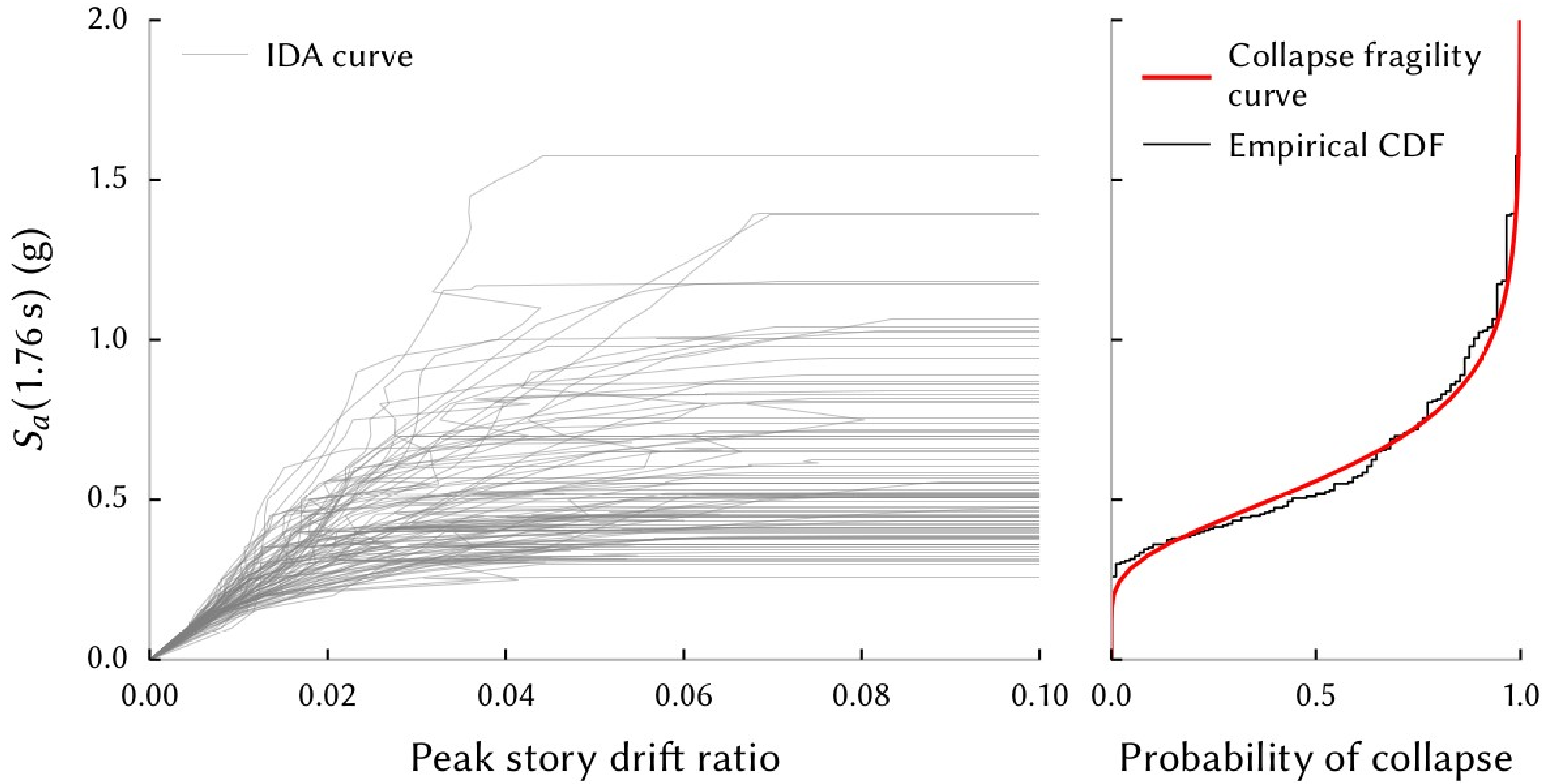
- Collapse fragility curve of a building quantifies its probability of collapsing under ground motions of different intensities

Structural collapse risk estimation



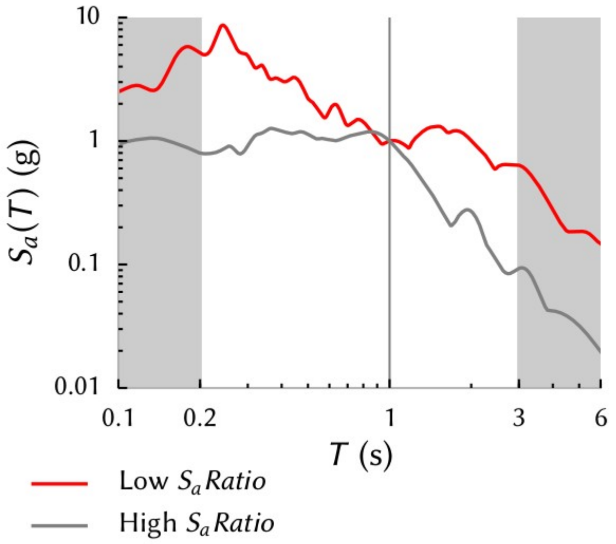
- Collapse fragility curve of a building quantifies its probability of collapsing under ground motions of different intensities
- Hazard curve quantifies the likelihood of observing ground motions of different intensities at the site
- Collapse risk, which is a function of the overlap between the two curves, needs to be determined for code-conforming buildings

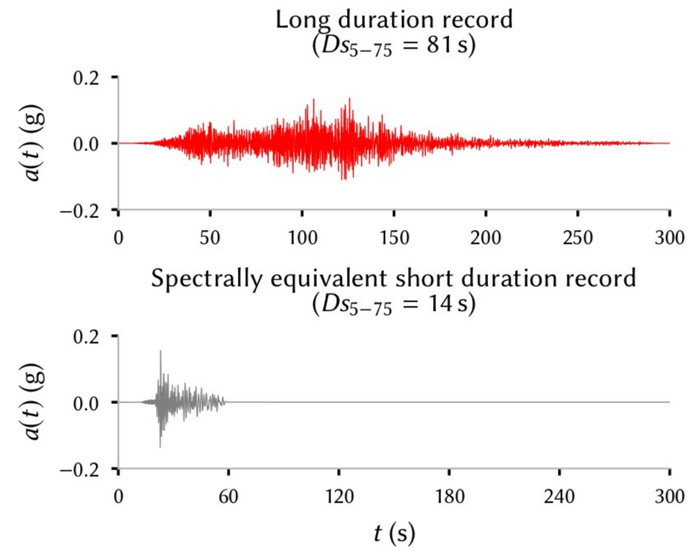
Using IDA to estimate the collapse fragility curve

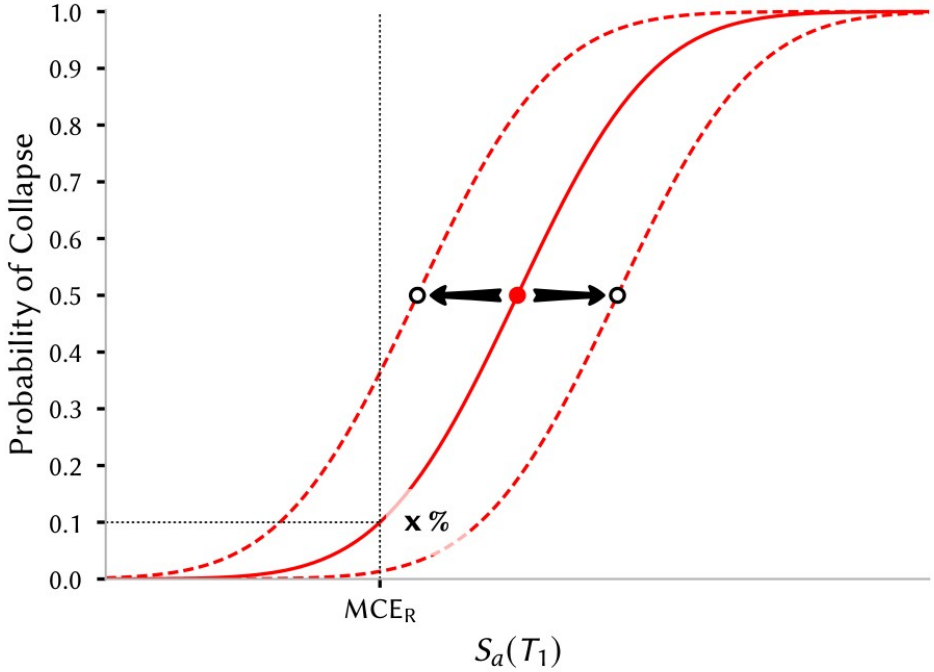


- (Typically generic) ground motions are incrementally scaled until they cause structural collapse
- A collapse fragility curve is fit through the estimated collapse intensities
- Recommended by FEMA P695, FEMA P-58, etc.

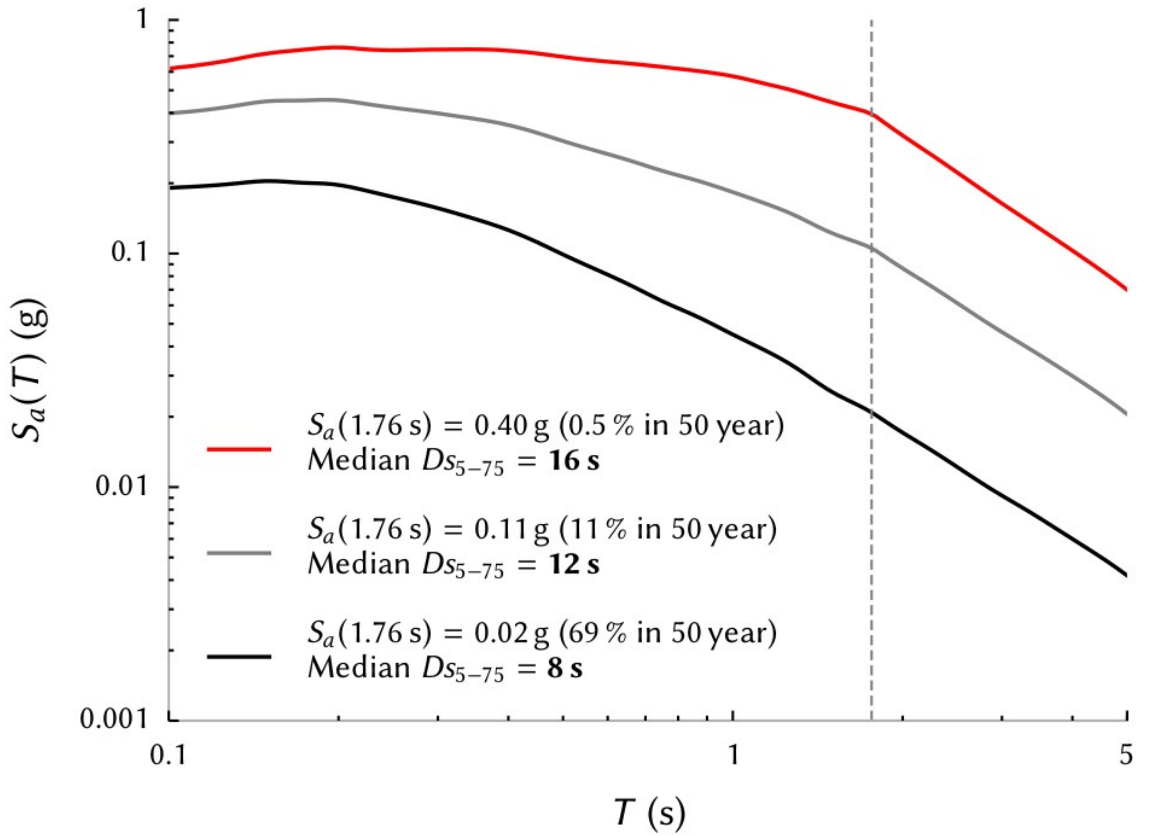
Ground motion characteristics influence the collapse fragility





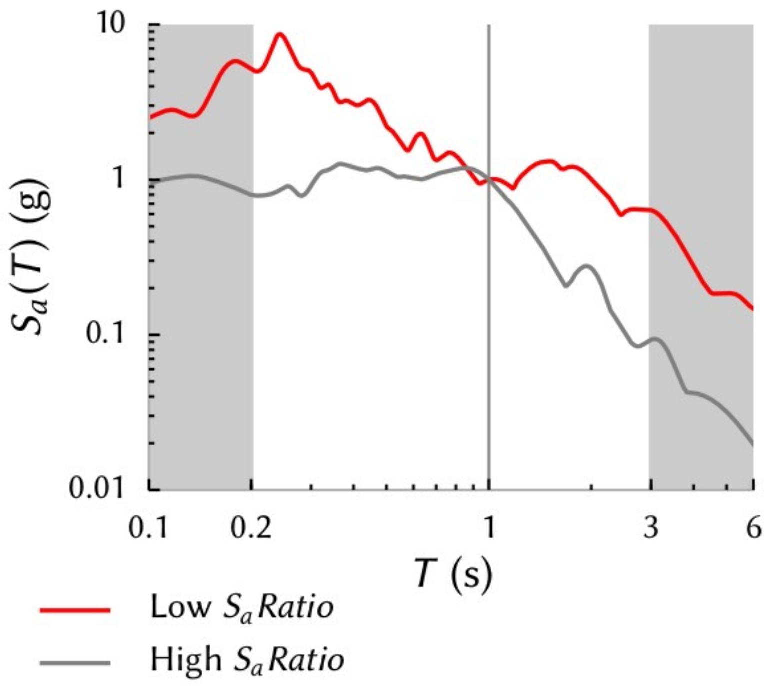


Limitations of IDA



- Does not account for the characteristics of the ground motions anticipated at the site
- Multiple stripe analysis accounts for them, but it requires site-specific record selection
- Developed a hazard-consistent IDA procedure (HC-IDA) that eliminates this drawback of IDA

Characterising response spectral shape

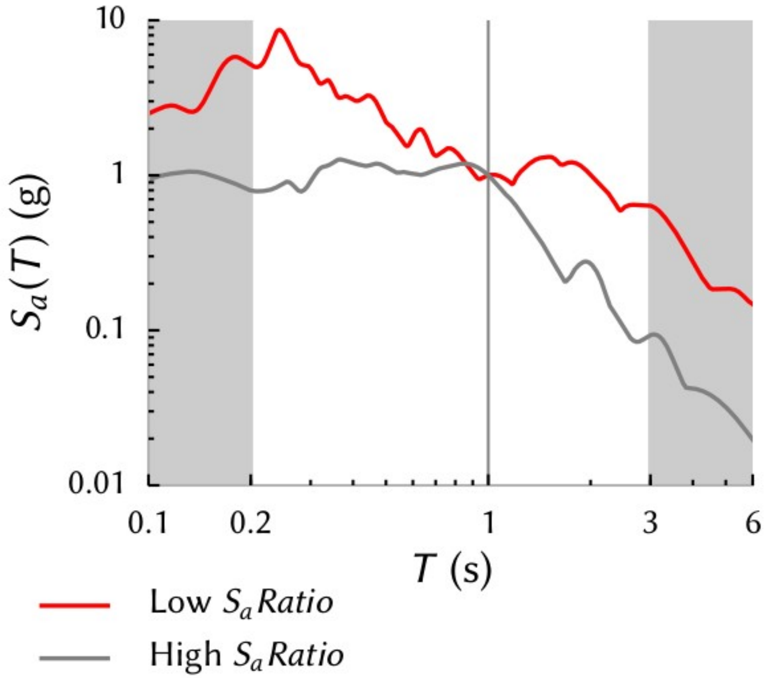


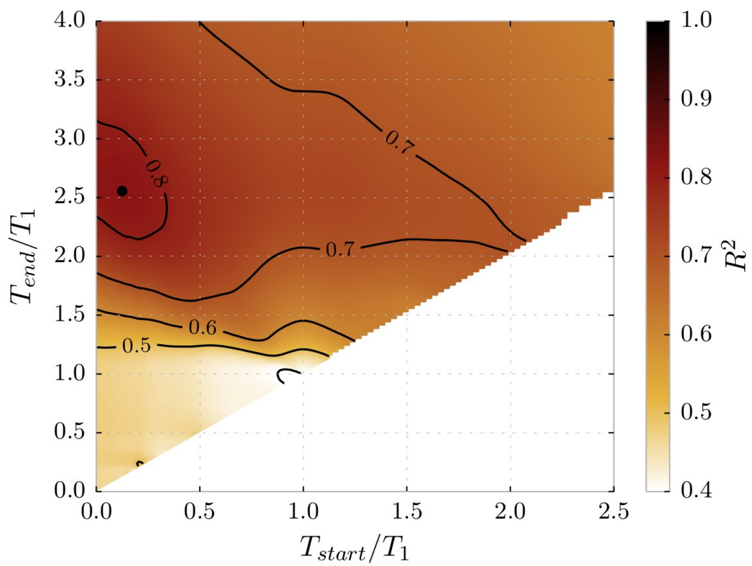
- S_aRatio is a dimensionless scalar metric of response spectral shape

$$S_aRatio(T, T_{start}, T_{end}) = \frac{S_a(T)}{S_{a,avg}(T_{start}, T_{end})}$$

$$S_{a,avg}(T_{start}, T_{end}) = \exp\left(\frac{\int_{T_{start}}^{T_{end}} \ln S_a(\tau) d\tau}{T_{end} - T_{start}}\right)$$

Characterising response spectral shape





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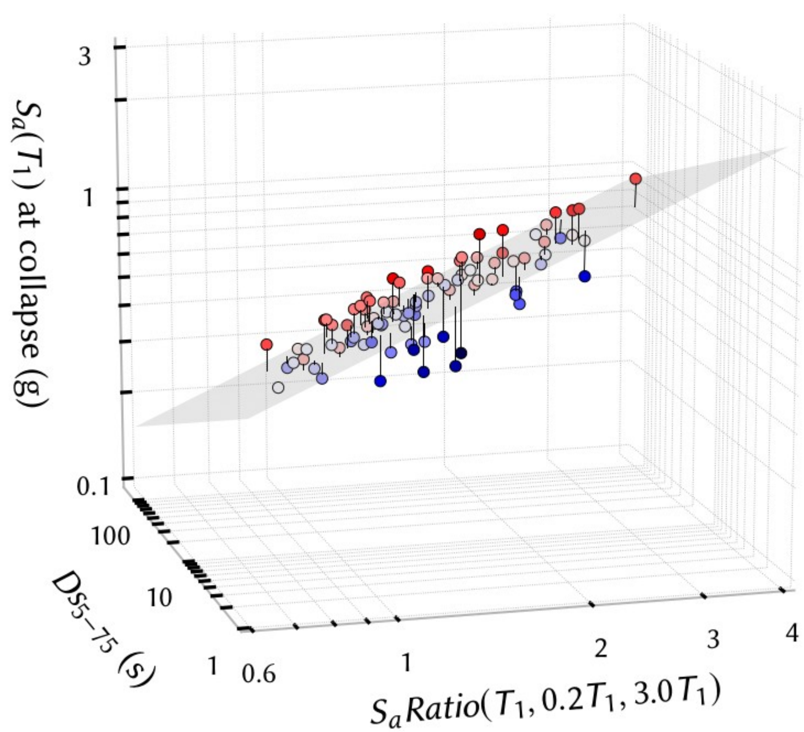
- It is typically computed using $T_{start} = 0.2T_1$ and $T_{end} = 3.0T_1$

Fitting the failure surface

$$\ln S_a(T_1) \text{ at collapse} = c_0 + c_{ss} \ln S_a Ratio + c_{dur} \ln Ds + \epsilon$$

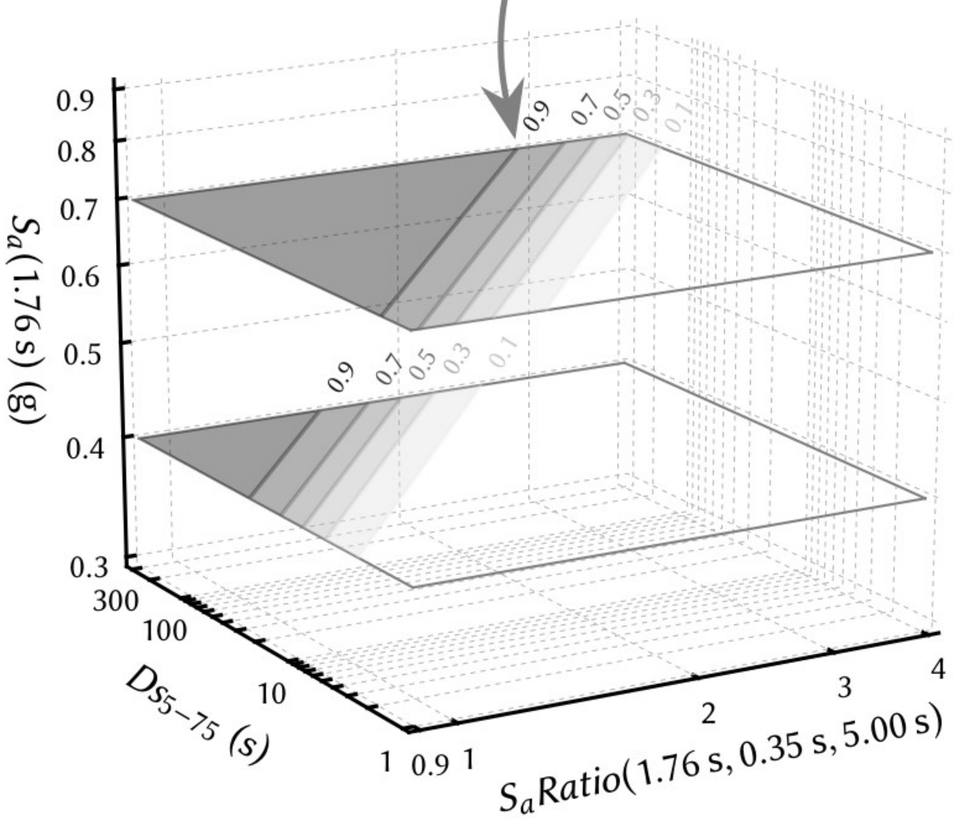


- SaRatio and duration can explain ~80% of the variability in the collapse intensities
- Records with low SaRatio values and long durations are more damaging
- Structure-specific failure surface quantifies

$$P\left[\text{collapse} \,|\, \ln S_a Ratio,\, \ln Ds,\, \ln S_a(T_1)\right]$$

Evaluating the reliability integral

$$P[\text{collapse} \mid \ln S_a(T_1)] = \iint P[\text{collapse} \mid \ln S_a Ratio, \ln Ds, \ln S_a(T_1)]\; f[\ln S_a Ratio, \ln Ds \mid \ln S_a(T_1)]\; d(\ln S_a Ratio)\; d(\ln Ds)$$



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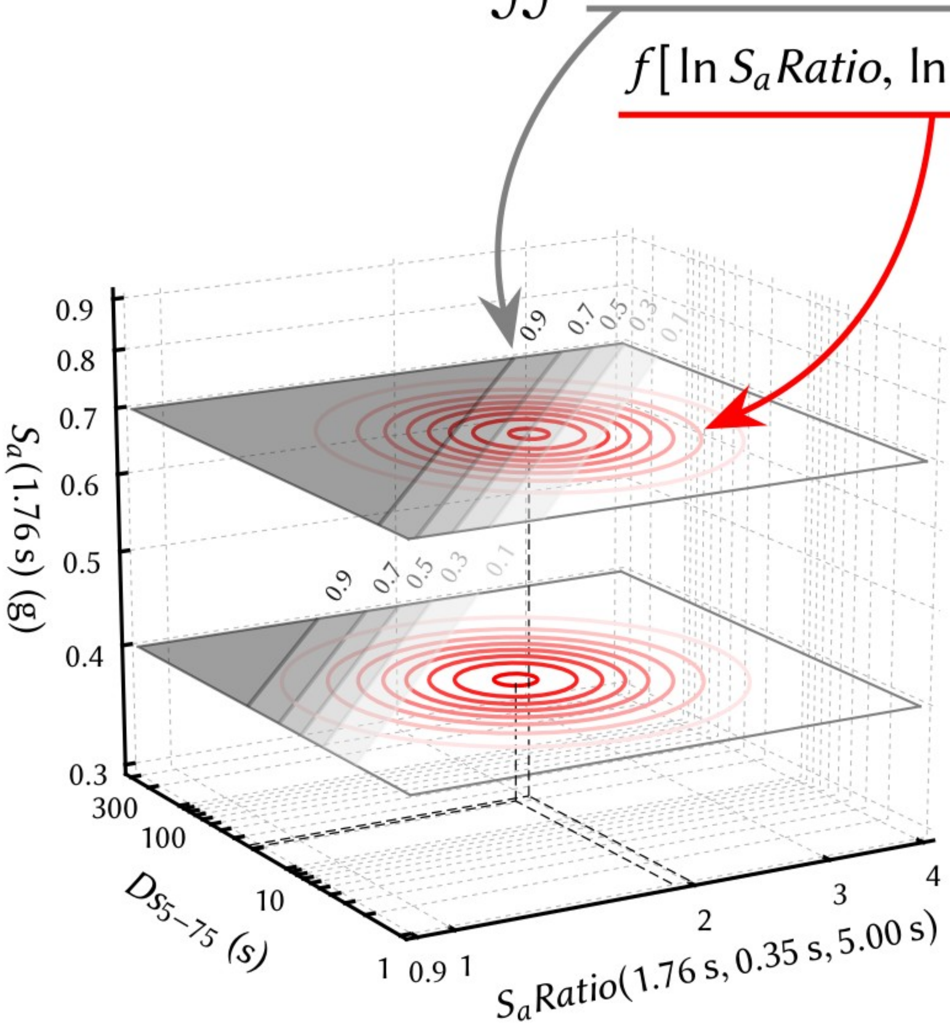
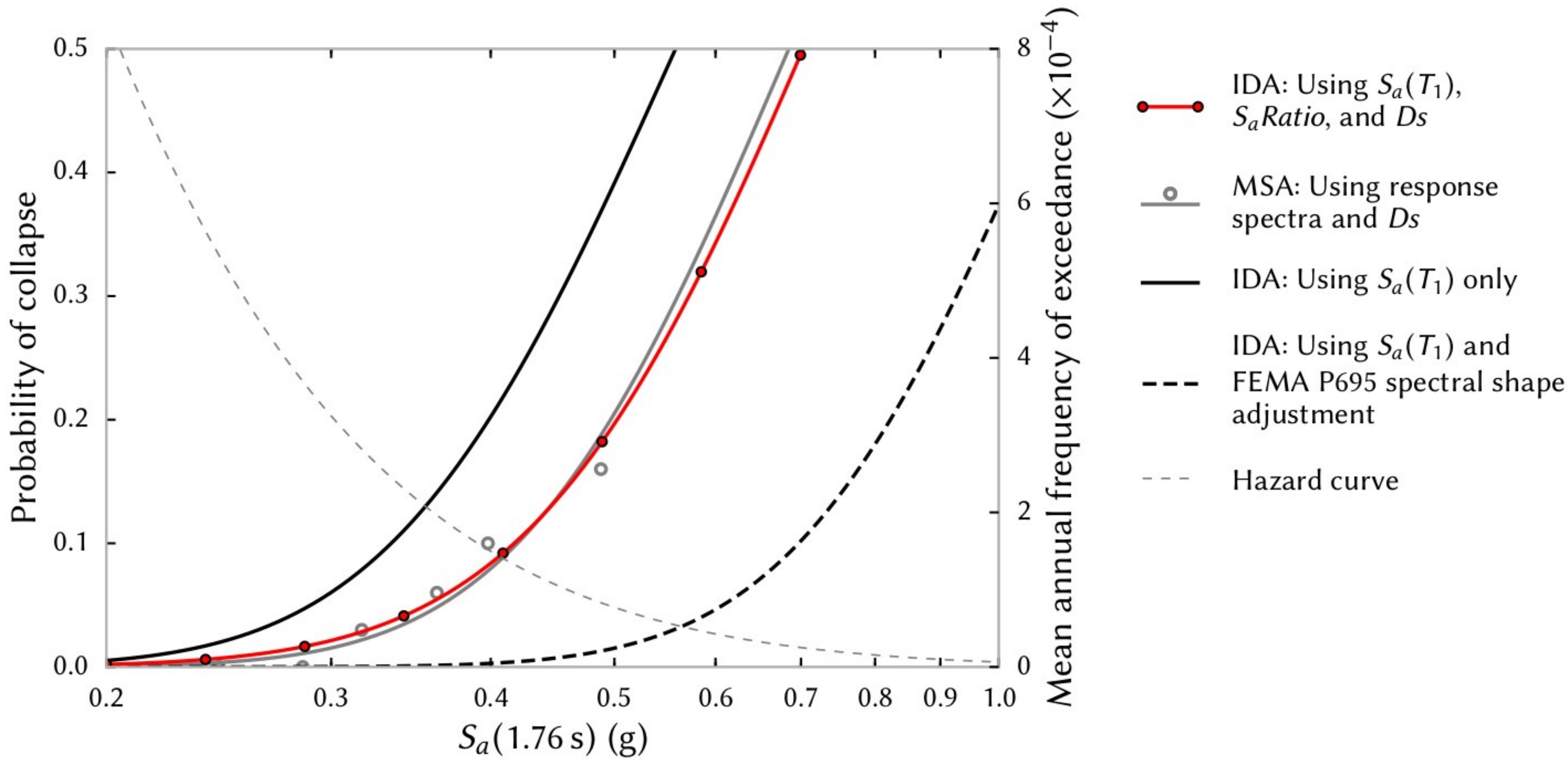


$f[\ln S_a Ratio, \ln Ds \mid \ln S_a(T_1)]$ characterizes the ground motions anticipated at a site; it can be computed using the GCIM framework

Degree of overlap between the contours determines the probability of collapse

Comparison of collapse fragility curves



- Results from the HC-IDA procedure agree well with hazard-consistent multiple stripe analysis (MSA)
- FEMA P695 incorporates an adjustment only for spectral shape; not for duration

Conclusion

- There is a need to benchmark the performance of buildings designed using NZS 1170.5
- Estimating the hazard-consistent collapse fragility curve of a building is an integral part of seismic collapse risk estimation
- The hazard-consistent IDA procedure (HC-IDA) overcomes the drawbacks of traditional IDA in collapse fragility estimation
- The collapse fragility curve estimated using HC-IDA agrees well with hazard-consistent multiple stripe analysis