3D Stress Modeling in Hyuga-Nada, Southwestern Japan: Geophysical Analysis with Focus on Seamounts and Stress Changes in Thrust Faulting Stress Regions

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Introduction

Hyuga-Nada, located in the western region of the Nankai Trough, is a tectonically complex area characterized by the subduction of the Philippine Sea Plate beneath the Eurasian Plate. This region is well-known for various seismic phenomena, including frequent small earthquakes and significant slow slip events (SSEs). One of the defining features of the Hyuga-Nada subduction zone is the presence of seamounts on the oceanic plate. These seamounts play a crucial role in affecting the stress regime and faulting behavior within the area.

Our research focuses on the 3D stress modeling of the Hyuga-Nada subduction zone, particularly analyzing the interaction of two seamounts within the subduction zone and their influence on the stress state of the region. We aim to investigate the stress changes in the thrust faulting region and explore their relationship with slow slip events (SSEs). This report presents the geological and geophysical introduction of the area, the methodology applied in the 3D stress modeling, and a discussion of the results, particularly how these stress changes correlate with SSEs.

Geological and Geophysical Setting of Hyuga-Nada

Hyuga-Nada sits at the northern part of the Philippine Sea Plate, where the plate subducts beneath the Eurasian Plate along the Nankai Trough. The subduction zone is highly active, with numerous seismic activities recorded, ranging from shallow earthquakes to deeper tremors and SSEs.

1. **Tectonic Setting**:

- The Nankai Trough forms a convergent boundary where the Philippine Sea Plate is thrust beneath the Eurasian Plate at a rate of approximately 4-6 cm per year. This process is responsible for generating large interplate earthquakes, including the anticipated Nankai megathrust earthquakes.
- Hyuga-Nada is located between the forearc basin of the Kyushu region and the Nankai Trough's deeper portion, which makes it an essential area for studying stress accumulation and release associated with subduction.

2. **Geological Features**:
   - The region consists of marine sediments on the oceanic plate and highly deformed accretionary wedges formed due to continuous compression from plate subduction. These wedges contain numerous faults that are reactivated by tectonic stresses.
   - Seamounts are prominent geological structures on the subducting plate. These topographic highs act as asperities on the plate interface, affecting the stress distribution, locking behavior, and overall tectonic dynamics of the region.
3. **Slow Slip Events (SSEs)**:
   - Hyuga-Nada is known for its recurring SSEs, occurring at a depth of around 30-40 km along the plate interface. These events are associated with episodic, aseismic slips that release stress over weeks to months, and they may be precursors to larger earthquakes.
   - The relationship between SSEs and faulting in the region is complex, but it is hypothesized that the stress changes resulting from the presence of seamounts may influence the timing and magnitude of these events.

3D Stress Modeling Methodology

To understand the stress state in Hyuga-Nada, particularly in areas influenced by seamounts and their potential impact on slow slip events, we constructed a 3D finite element model. This model incorporates the geological and geophysical characteristics of the region, including the presence of two major seamounts on the subducting Philippine Sea Plate.

1. **Model Geometry**:

   - The 3D model spans approximately 200 km in length and 100 km in depth, capturing the key features of the Hyuga-Nada subduction zone, including the plate interface, the overriding Eurasian Plate, and the subducting Philippine Sea Plate.

   - The seamounts were modeled as topographic highs with dimensions based on bathymetric data. These seamounts protrude into the plate interface, causing local changes in stress and strain fields. (Figure 1)

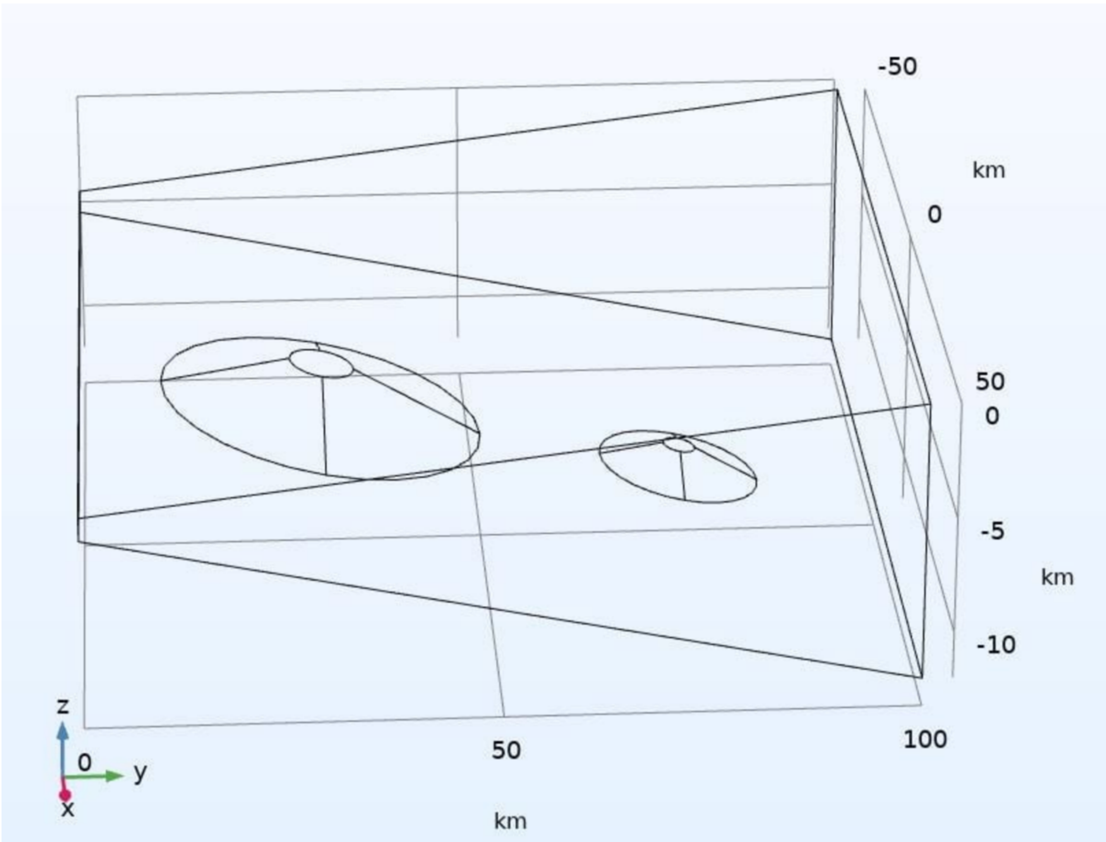

Figure 1: The 3D stress model geometry in this study

2. **Material Properties**:

   - The materials of both the oceanic and continental plates were modeled using elastic and viscoelastic properties based on available seismic and geophysical data. The accretionary wedge and fault zones were assigned weaker, more compliant properties to reflect their highly deformed and fractured nature (Table 1).

Table 1: Material Properties

Parameter	Value
X_dir	100km
Y_dir	100km
Z_dir	7.5km~12km
Sea_mount_L	Radius: 15km, height: 1.5km
Sea_mount_R	Radius: 8km, height: 1km
Sea_mount_prop, Base_prop (red)	Young's modulus: 3.8e10 Pa
	Poisson ratio: 0.27
	Density: 2800 kg/m^3
top_prop (blue)	Young's modulus: 2e10 Pa
	Poisson ratio: 0.35
	Density: 2350 kg/m^3

3. **Boundary Conditions**:

Plate convergence was simulated with velocity boundary conditions based on GPS measurements of plate motion in the region. For the consistency of each element, we fixed the boundary to prevent the local dislocation (fault). Stress accumulation was allowed to evolve over time, simulating the slow convergence process that leads to stress build-up around the seamounts to the balance.

This model includes the different Poisson ratio in the the plate interface, also consider the vertical stress and sea water weight to account for the heterogeneity introduced by the seamounts.

4. **Stress Analysis**:

The stress field was calculated throughout the model domain, focusing on the stress concentrations around the two seamounts and along the thrust faults stress region ($S_{HMAX} > S_{hmin} > S_v$) in the accretionary wedge. We particularly examined the stress changes in areas associated with SSEs, where periodic stresses disturbance are observed.

Results

The results of the 3D stress modeling reveal several key insights into the stress regime of the Hyuga-Nada subduction zone is listing in foloowing

The presence of seamounts significantly alters the stress field in their vicinity. In particular, we observed elevated normal and confining stresses around the seamounts, particularly where they intersect the plate interface. These stress concentrations could explain the locking behavior in certain segments of the subduction zone, where seismic coupling is higher.

The stress concentration around the seamounts suggests that these features act as asperities, influencing the overall behavior of the stress state. Regions of increased stress may act as nucleation points for slow slip events or even larger seismic events.

In the thrust faulting region of the accretionary wedge, stress was found to accumulate and release in a cyclical manner, with higher stress near the seamounts. This finding suggests that the interaction between the overriding plate and the subducting seamounts can influence the mechanis and location of slow slip events. In this model, we observed that the stress state in the thrust faulting region periodically changes in response to SSEs. As slow slip occurs along the deeper portion around the sea mounts, stress is relieved in the lower sections the friction is . This transfer of stress could lead to increased SSEs over time. (Figure 2)

The model suggests that the stress state in the seamount regions could act as a trigger for SSEs by altering the local stress regime in a way that promotes aseismic slip rather than seismic rupture. This finding is consistent with the hypothesis that seamounts play a crucial role in modulating the seismic and aseismic behavior of the fault zone.

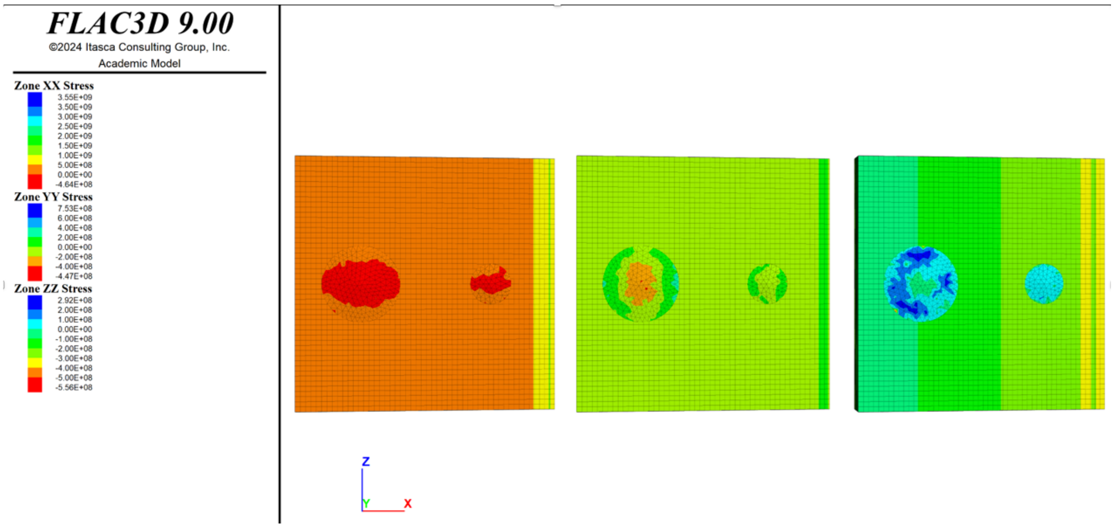

Figure 2: Top view of stress variation in thrust faulting stress regime.

Discussion and Implications

The results of this 3D stress modeling have significant implications for understanding the tectonic dynamics of Hyuga-Nada and the broader Nankai Trough region. The interaction between seamounts and the plate interface creates a complex stress regime that influences both seismic and aseismic faulting processes.

1. **Seismic Hazard Assessment**:
   - The presence of seamounts and their influence on stress concentrations highlight the potential for increased seismic hazard in the Hyuga-Nada region. While slow slip events are largely aseismic, the stress changes associated with these events could lead to larger, seismic ruptures in the future.
2. **Role of Seamounts in Slow Slip Events**:
   - The correlation between seamount-induced stress changes and SSEs underscores the importance of considering topographic features in seismic hazard models. Understanding how these features influence the stress state can provide valuable insights into the mechanisms that control slow slip and earthquake generation.

Conclusion

This research provides a new approach into the stress regime of Hyuga-Nada, particularly in regions influenced by seamounts on the subducting Philippine Sea Plate. The 3D stress modeling highlights the complex interplay between seamounts, Nankai subduction zone, and SSEs, and discuss the importance of incorporating these features into seismic hazard assessments. Future studies should continue to explore the relationship between topographic features and seismic phenomena to improve our understanding of earthquake and SSE behavior in Nankai subduction zones.