Thrust development in the north of Nankai Trough : A finite element method approach

Bull. Fac. Sci., Univ. Ryukyus, No.80 : 25 – 35 (2005)

Thrust development in the north of Nankai Trough: A finite element method approach

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Abstract

In this study, we propose the cause of thrusting in Nankai Trough off cape of Muroto using Finite Element Method (FEM). Our models are based on cross-section produced by Moore et al. (2001). We divide the section into eight layers. During calculation we change rock layer properties of Landward Dipping Reflector Zone (LDRZ), oceanic crust and hypothetical seismogenic zone. Overall results of the modelling suggest that the seismogenic zone controls the thrust development in the region.

Introduction

In Japan, there are many studies on seismology giving emphasis on earthquake events and induced damages. The calculation of the place and scale of earthquake events is a matter of great urgency before the next great earthquakes. Nankai Trough is one of the important areas to study seismicity and development of thrust system in accretionary prism. Recently, in Nankai Trough, many studies have been carried out in different aspects which are mainly concentrated to geological structures. For example, Park et al. (1999) succeeded in imaging a subduction seamount, using a multi-channel seismic (MCS) reflection survey. Moore et al. (2001) investigated the detail structure of the Nankai Trough. They divided whole area into different thrust system. Nakanishi et al. (2002) well documented earthquake events in the area. They estimated recurrence interval between 100 and 200 years. The last earthquake occurred in 1946, which means we are in interseismic period. This area is the site proposed for IODP in 2006. In this study, we have simulated the stress state of Muroto Transect to understand the cause of the large thrusting in the Nankai Trough considering both décollement and seismogenic zone.

Received: June 30, 2005

Geological setting

The Nankai Trough is the plate boundary between the Eurasian plate and the Philippine Sea plate off Southwest Japan (Fig. 1). The Philippine Sea Plate is subducting at low-angle beneath the Eurasian plate to the NNW. The accretionary prism was formed from NW of Nankai Trough to the Shikoku Island. In the Shikoku Island, the outer zone of Southwest Japan is considered as an ancient accretionary prism (Fig. 2). In this study, we simulate the model for Muroto Transect (seismic line 141-2D of Moore et al., 2001;Fig. 3) which crosses the trough axis. In this section, there are some core data. For example, in site 808 bore holes were penetrated into the trench turbidite facies, Upper Shikoku Basin facies, Lower Shikoku Basin facies and Oceanic crust (Ujiie et al., 2001). The Muroto Transect is divided into five thrust zones (Fig. 3); from seaward, Protothrust Zone (PTZ), Imbricate Thrust Zone (ITZ), frontal Out-Of-Sequence Thrust zone (OOST), Large Thrust-

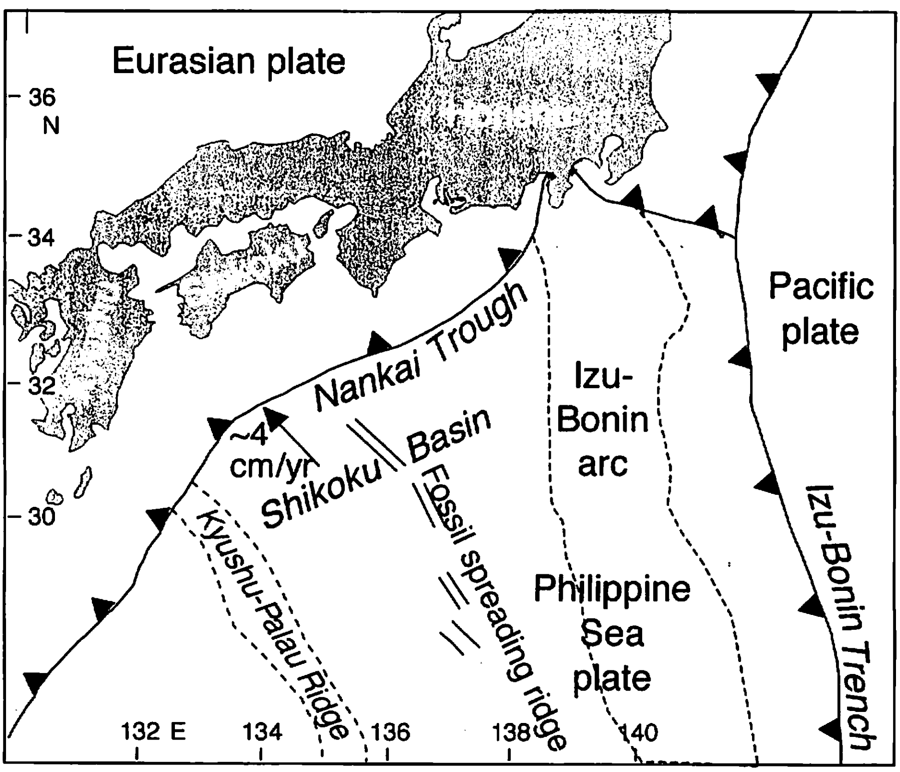

Fig. 1. Plate boundary around the Nankai Trough (Moore et al., 2001). The convergence ratio is ca. 4 cm/a.

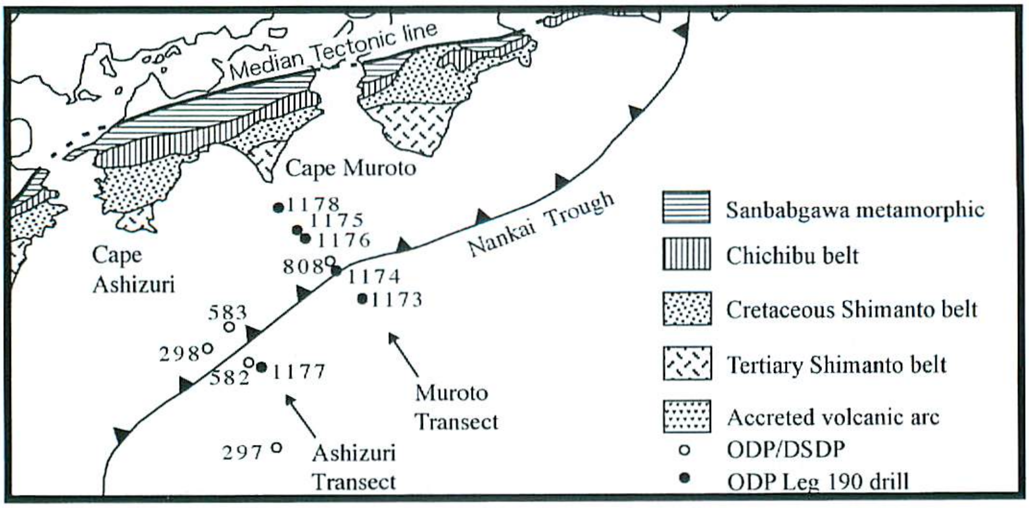

Fig. 2. Geological map at outer zone of Southwest Japan (Moore et al., 2001).

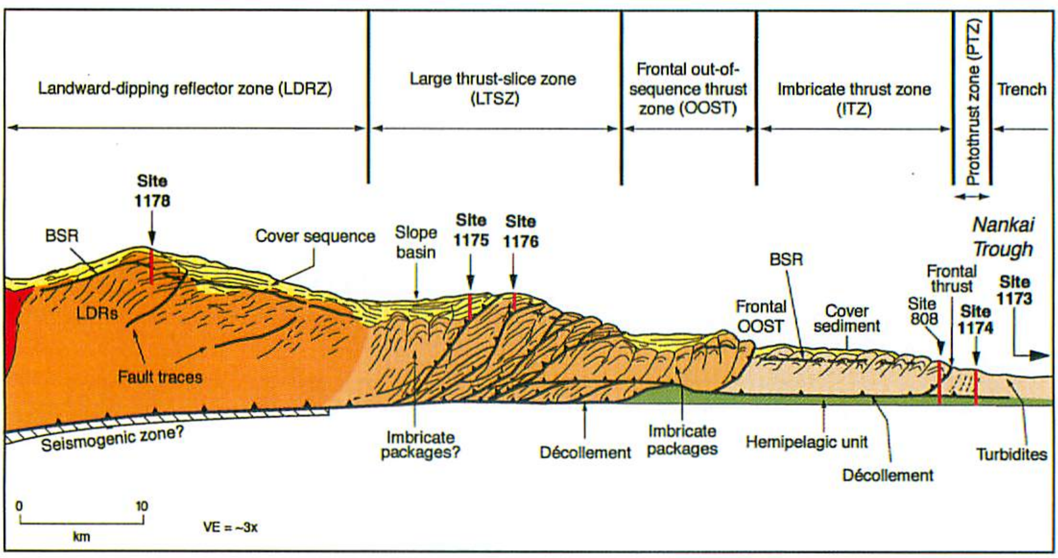

Fig. 3. Schematic interpretation of Muroto Transect by Moore et al. (2001).

Slice Zone (LTSZ) and Landward-Dipping Reflector Zone (LDRZ) (Moore et al., 2001). In their study, PTZ is interpreted as the incipient deformation zone and developed the initial décollement. Above the décollement, the thickness of sediments increases to the landward. ITZ is characterized by the imbricate structure. OOST is composed of younger generation thrust fault system, because this fault system cut the preexisting sequence of imbricate thrust. In LTSZ, there are four features. (a) Out-of-sequence thrust is composed of tectonic slices of either previously imbricated packages or relatively coherent sedimentary sequences. (b) The coherent slices are observed in the stratified layers. (c) Slope sediments show landward dipping which suggests recent active uplift. (d) Bottom-Simulating Reflectors (BSRs) are weakly detected and undeveloped. LDRZ is characterized by landward dipping and semicontinuous strong reflectors. The developed BSR suddenly vanishes in the LTSZ (Moore et al., 2001)

Modeling

In this paper, we have simulated fault pattern using 2D Finite Element Method (FEM) under plane strain condition. We suppose that the section along the Muroto Transect as elastic plane.

Finite Element Method (FEM)

FEM is one of the techniques analyzing of geological structures. This method can calculate deformation through simplification of the section by dividing objects into several elements.

Geometry and boundary condition

Firstly, we divide the geological cross-section of eight layers into triangular elements. In our models, we consider OOST and LTSZ as a single tectonic slice named as Large Thrust Zone (LTZ) for the simplicity in calculation. Consequently, we divide our model into eight layers from bottom to top, oceanic crust, décollement zone, seismogenic zone, Accretionary Prism Toe Zone (APTZ), Imbricate Thrust Zone (ITZ), Large Thrust Zone (LTZ), Landward-Dipping Reflector Zone (LDRZ) and cover sediment (Figs. 4 and 5). Since

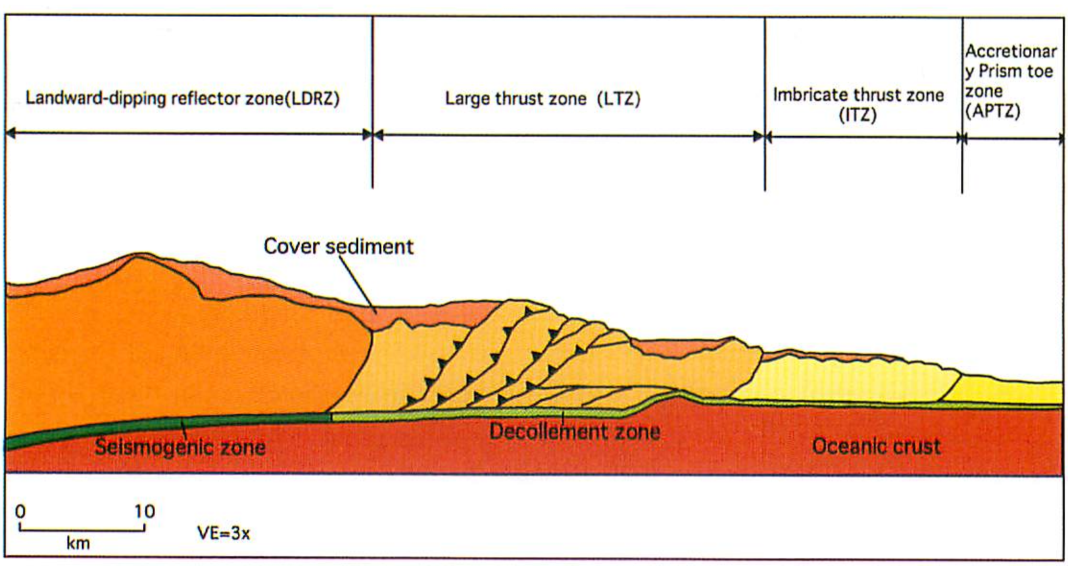

Fig. 4. Simplified section from Figure 3.

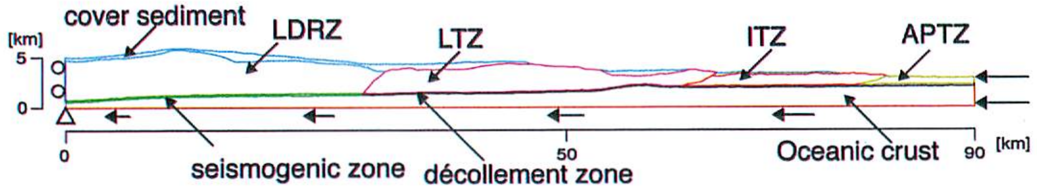

Fig. 5. Layer division and boundary condition

the ratio of length and width is 1:3 in the cross-section, we simply expand length three times.

We impose adequate boundary condition as shown in Fig. 5. The basal part of the model can move horizontally whereas upper part is free to move in any direction. We apply convergence displacement from 0 m to 200 m in the right hand side of the model. However left hand side of the model is free to move vertically but fixed in horizontal direction. The triangle indicates the fixed nodal point in all direction. The displacement in bottom gradually decreases to landward.

Rock layer property

We use suitable rock layer properties shown in Table 1 for the standard model (Model 1). These properties are based on the studies carried out by Baba et al. (2001), Pauselli et al. (2003) and Takahashi et al. (2002). We change rock layer property of seismogenic zone in each model as shown in Table 2.

Table 1. Standard rock layer property.

	Poisson's ratio	density (kg/m^3)	Young's modulus(GPa)	cohesion (MPa)	friction angle (degree)
Oceanic crust	0.25	2800	105	170	55.0
Décollement zone	0.40	2200	0.1	6	20.0
Seismogenic zone	0.40	2200	0.1	6	20.0
LDRZ	0.37	2200	30	17	35.0
LTZ	0.37	2000	30	17	35.0
ITZ	0.36	2000	18	17	35.0
APTZ	0.35	2000	18	17	35.0
Cover sediment	0.45	1500	1	17	30.0

Table 2. Rock layer property of seismogenic zone.

	Poisson's ratio	density (kg/m³)	Young's modulus(GPa)	cohesion (MPa)	friction angle (degree)
Mode 1	0.40	2200	0.1	6	20.0
Mode 2	0.40	2200	0.17	6	20.0
Mode 3	0.40	2500	0.1	6	20.0
Model 4A and 4B	0.25	2800	105	170	55.0
Model 5A and 5B	0.37	2200	30	17	35.0

Results

1. Model 1 (standard model)

The rock layer properties of the seismogenic and the décollement zone are of the same value. In this model, there is no failure element under the displacement boundary condition between 0 m and 100 m. With increasing displacement few failure elements are observed in shallow part of ITZ (Fig. 6).

2. Model 2

In this model, we increase Young's modulus of seismogenic zone from 0.1 GPa to 0.17 GPa. We obtain failure elements under 200 m boundary displacement in shallow part of ITZ (Fig. 7). This result is almost the same as that of Model 1.

3. Model 3

We increase density of seismogenic zone from 2200 kg/m³ to 2500 kg/m³. Some failure elements are observed at shallow part of ITZ (Fig. 8). This result is also similar to that of Model 1.

4. Model 4A

Both the rock layer properties of the seismogenic zone and the oceanic crust are same in this model. The failure elements under 0 m, 100 m and 200 m boundary displacements are shown in Fig. 9. The result of this model is different with that of above models (Models 1, 2 and 3). Many failure elements are concentrated at the boundary of LTZ/LDRZ. Because this happens under 0 m boundary displacement, this failure occurred due to gravity. We also observed few failure elements under 100 m and 200 m boundary condition.

5. Model 4B

The model has the same rock layer properties of model 4A except for being equal the density of LDRZ and LTZ.

6. Model 5A

Both the rock layer properties of the seismogenic zone and LDRZ are same in this model. We obtain almost the same distribution of failure elements with Model 4A as shown in Fig. 10.

7. Model 5B

The model has the same rock layer properties of model 5A except for being equal the density of LDRZ and LTZ.

Discussion

Distribution of the failure elements of each model is shown in Figs. 6 to 10. We will discuss each model separately.

1. In Model 1 (Fig. 6), if property of seismogenic zone is equal to décollement zone, there are few failure elements within LTZ. Therefore, we think, if the seismogenic zone are continuous to the décollement zone, no large thrusting occur within LTZ.

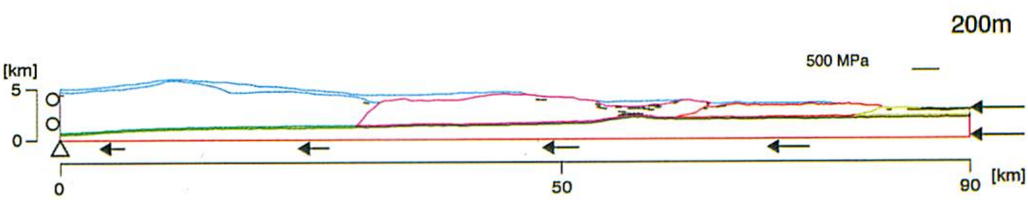

Fig. 6. Distribution of failure elements in Model 1 under 200m convergence displacement.

2. In Model 2 (Fig. 7) and Model 3 (Fig. 8), failure distributions of both models do not show significant difference if changing the value of Young's modulus and density slightly. Little change in Young's modulus and density does not affect the thrust development in LTZ.

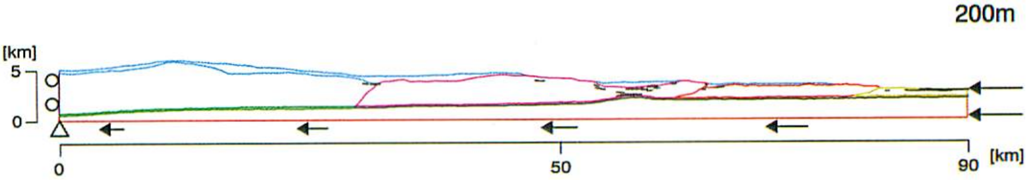

Fig. 7. Distribution of failure elements in Model 2 under 200m convergence displacement increasing Young's modulus of seismogenic zone.

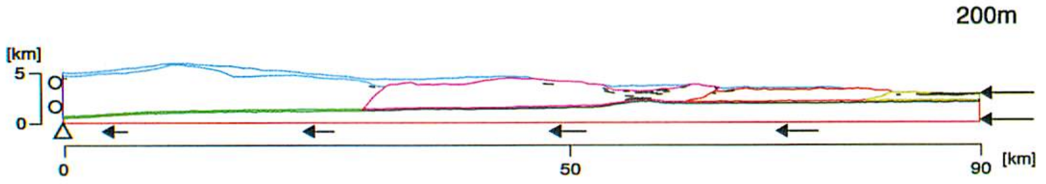

Fig. 8. Distribution of failure elements in Model 3 under 200m convergence displacement increasing density of seismogenic zone.

3. In Model 4A (Fig. 9) and Model 5A (Fig. 10), many failure elements are concentrated along the boundary between LTZ and LDRZ, so that the seismogenic zone has affected the thrusting within LTZ.

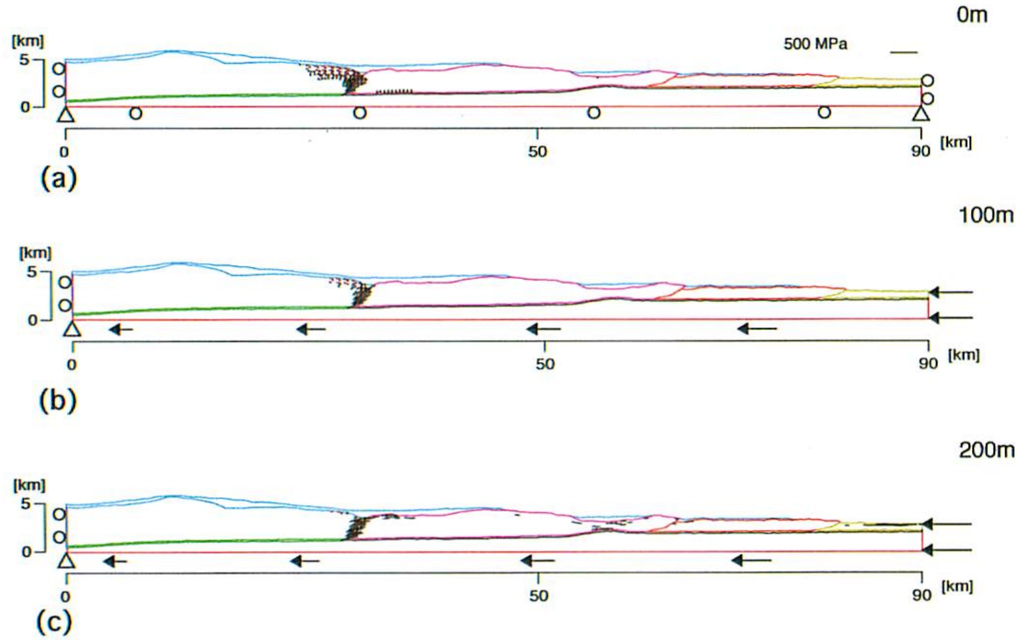

Fig. 9. Distribution of failure elements in Model 4A under 0m, 100m and 200m convergence displacement where rock layer properties of seismogenic zone and oceanic crust are same.

4. If decreasing the density of LDRZ to 2000kg/m^3, which means the density of LDRZ and LTZ is equal, there are no difference on failure elements where we call these models as model 4B and 5B as shown in Fig.11 and 12, so that we think that the difference of density between LTZ and LDRZ does not affect the thrusting in LTZ.
5. Since the rock layer properties of LDRZ and LTZ in model 4B and 5B are equal, two zones of LDRZ and LTZ are considered to be one zone. There is a condensed failure zone between the boundary of LDRZ and LTZ, then we consider the boundary of the seismogenic zone and décollement zone affects the thrust generation within LTZ.

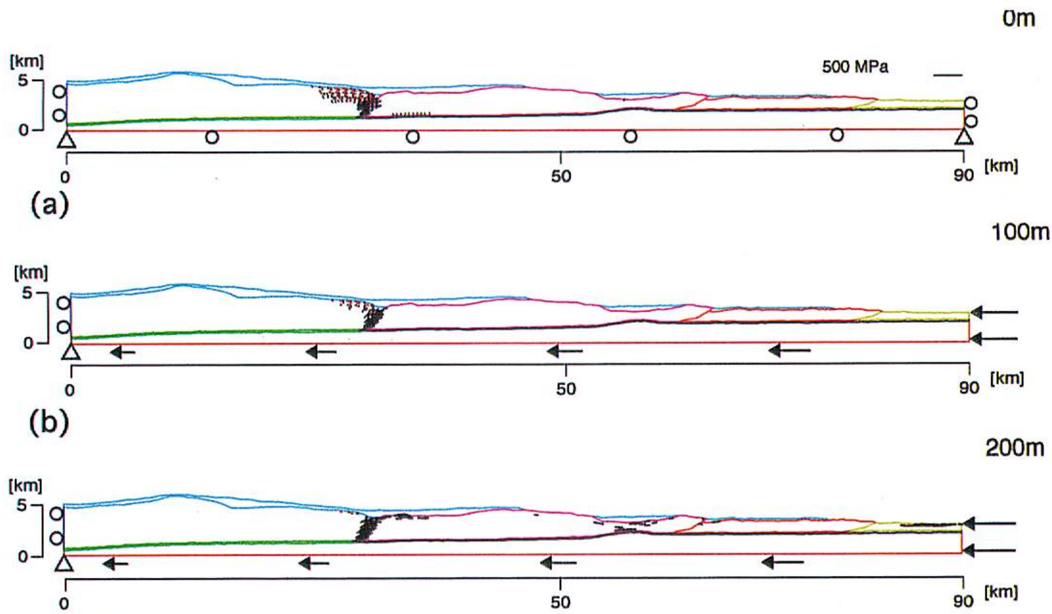

Fig. 10. Distribution of failure elements in Model 5A under the 0m, 100m and 200m convergence displacement where rock layer properties of seismogenic zone and LDRZ are same.

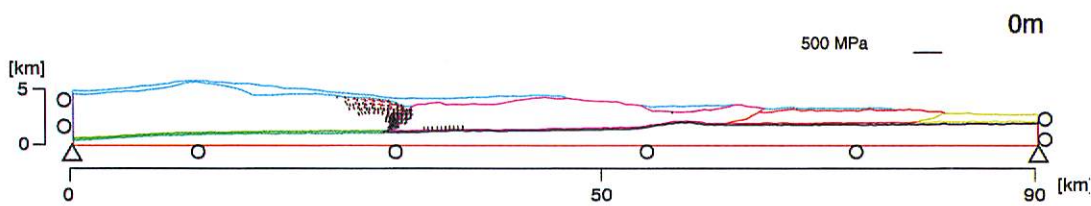

Fig. 11. Distribution of failure elements in Model 4B under 0 m convergence displacement where rock layer properties of LDRZ and LTZ are same.

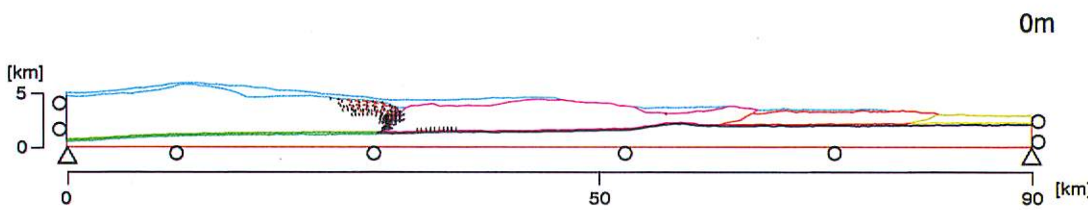

Fig. 12. Distribution of failure elements in Model 5B under 0 m convergence displacement where rock layer properties of LDRZ and LTZ are same.

6. In several models (Models 1, 2, and 3), under less than 200m boundary displacement, there are no failure elements. These outcomes disagree with those by some authors (Nakanishi et al., 2002, Kodaira et al., 2000) about seismicity. Since recurrence interval for the Nankai earthquake is estimated 100 - 200 years, considering the convergence

rate 4cm/a the resultant displacement is calculated as 4m - 8m which is the cause of failure elements in the area. It seems that the boundary conditions of 100 m and 200m are larger than this estimated value 4m - 8m.

Conclusion

We considered that the seismogenic zone was a weak and thin layer which caused the large thrust within LTZ. While the simulated results suggest that seismogenic zone is a rather strong and thin layer as the oceanic crust or LDRZ. As there are not enough data, we cannot decide the properties of seismogenic zone. Results of the simulation show that seismogenic zone influences the thrust development in the Nankai accretionary prism. Future model should consider more reasonable boundary condition and rock layer properties to understand the mechanism of thrust development in the Nankai accretionary prism.

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