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# Analysis of the 1976 Tangshan earthquake process

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**Abstract**

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A discrete crack model of the strain accumulation of the Tangshan rhombic block, together with slip and stable extension of the earthquake fault prior to and during the 1976 Tangshan earthquake, is presented. It includes two processes: frictional slip along the crack and stable extension of the crack tips. The finite element technique is used to calculate stress and deformation along the crack surface and stress intensity factors at the crack tips, and the Mohr–Coulomb principle is applied to judge the existence of frictional slip along the crack surfaces and to determine the crack extension direction using the maximum circumferential tensile stress criterion. The similarity between the data predicted by the model and the data collected during the field survey indicates that the crack model has successfully simulated the process of strain accumulation and fracture propagation prior to and during the Tangshan earthquake.

## Numerical model

The numerical model on the 1976 Tangshan earthquake is based on the concept of frictional contact of discontinuous solid surfaces and on the theories of stable extension of the crack, with the geodetic survey data and the focal mechanism solutions as the constraint conditions for simulation.

### *Concept of the crack model*

Triangulation data indicate: (1) that the Tangshan rhombic block was in a locked state prior to the Tangshan main shock, (2) the deformation of the Tangshan earthquake fault was very large during the main shock, but the adjustment in deformation after the earthquake was small, and (3) that consequently the Tangshan earthquake was due to sudden slip of the two walls of the Tangshan fault. Therefore, the rhombic block itself and its surrounding blocks may be treated as a contact system consisting of multiple deformable solid bodies, and the fault can be taken as two contact surfaces. We distributed a series of nodal pairs along the surface to form a set of contact elements. Special triangular elements with quarter-point nodes are used to deal with the stress singularity at the crack tip (Fig. 1). The stiffness equations are first separately formed for the different contact bodies and then linked up into the total stiffness equation, according to the boundary conditions for different contact states.

### *Treatment of boundary conditions*

Figure 1 represents the structure after discretization. It includes two types of boundary conditions. One of these is the exterior boundary condition, i.e. the distributive loading condition used in

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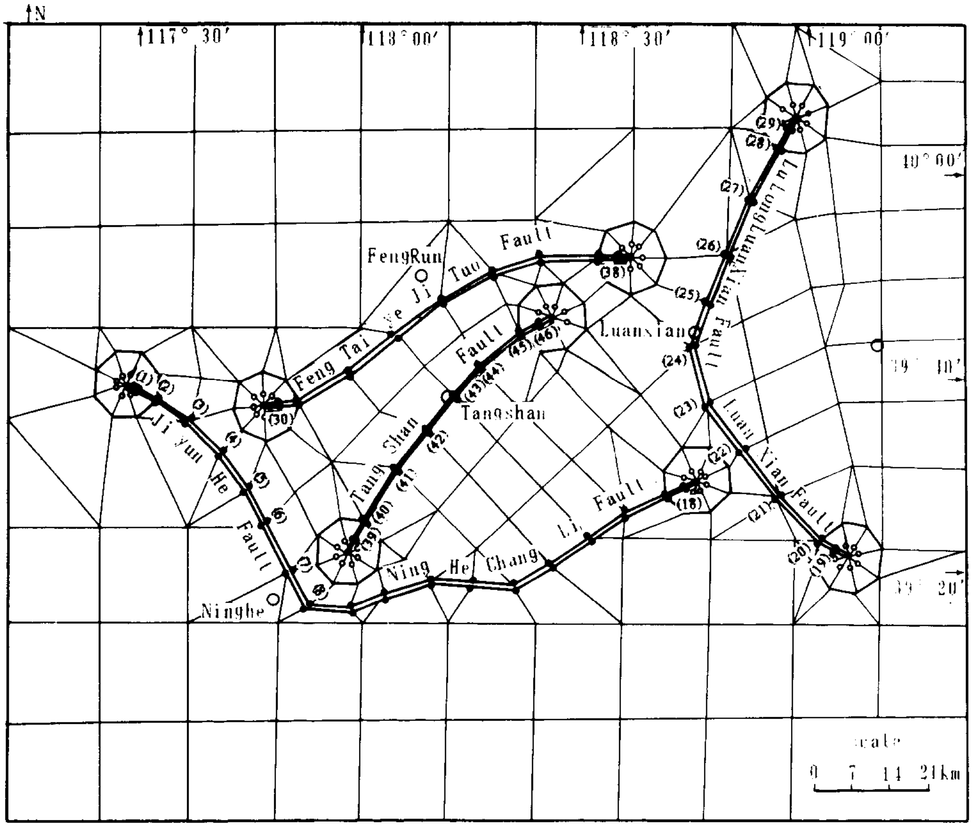


Fig. 1. Tectonic and finite element mesh map of the Tangshan rhombic block. The dots and circle form a series of nodal pairs along the surface to form a set of contact elements and the quarter-point node of the triangular elements, respectively. The numbers in parentheses indicate the sequence of nodal pairs.

this paper. The direction of the load is determined by the direction of the $P$-axis of the focal mechanism solutions, and its magnitude is obtained from inversion of the geodetic data. Another boundary condition is that along the crack surface, and it may be divided into the following three types: (1) the upper and lower surfaces of the crack are bonded together, i.e. the normal and tangential displacement differences are zero, (2) the two surfaces are separated, i.e. the normal and tangential stresses are constant or zero, and (3) the two surfaces slide over each other, i.e. the normal displacement differences and zero and the normal and tangential stresses follow frictional law, specifically the linear Mohr–Coulomb frictional law:

$$\begin{cases} \Delta U_n = 0 \\ F_s = C_0 + \mu F_n \end{cases} \tag{1}$$

where $C_0$ and $\mu$ are the cohesion strength and frictional coefficient along the crack surface, respectively (Chan and Tuba, 1971), and $F_s$ and $F_n$ are tangential stress and normal stress, respectively. $\Delta U_n$ represents the normal displacement differences between the double nodal points at the crack surface.

The solution to the deformation problem of solid bodies is contact with each other must satisfy not only the exterior loading condition, but also the contact boundary conditions listed above.

It is thus a problem of a stationary value with constraint conditions. Introducing Lagrange constraint factors $\lambda$, we obtain the functional of the following constrained variation:

$$\Pi^* = \Pi + \int_{\Gamma_{CL}}^{T} \lambda \Delta U_d T \tag{2}$$

where $\Pi$ is the functional of the general elastic deformation problem, $\lambda = (\lambda_1, \lambda_2)^T$ are the Lagrange constraint factors correspo normal and tangential stresses alo surface, $\Delta U = (\Delta U_n\ \Delta U_s)^T$ is the displa