利用*W* 波相逆推震源參數與單位海嘯建立琉球海域海嘯預警系統(II)

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1. Introduction

The historic tsunami hazards in Taiwan tend to occur in the north and southwest coasts (Fig. 1). The Ryukyu trench offshore northeast Taiwan, with its NE-SW stretch more than 1000 km, is a potential zone of significant tsunamigenic earthquake to occur, which will cause widespread tsunami hazards in Taiwan. In this study, we propose to establish a seismic tsunami warning system in Taiwan for earthquakes in the Ryukyu trench by combining *W* phase inversion and unit tsunami method.

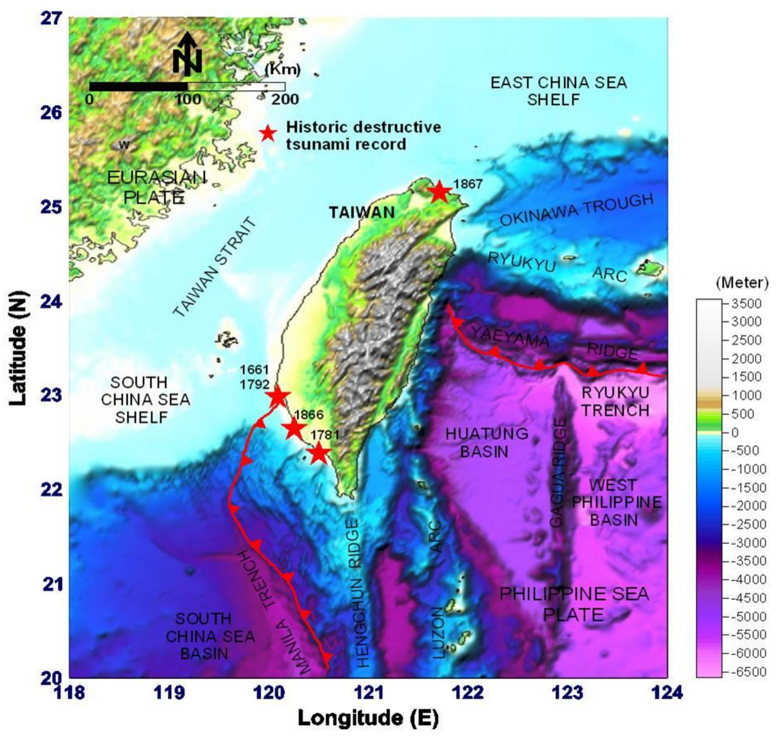

Fig. 1. Locations of historical tsunami hazards in Taiwan. Note the most distribute on North and SW Taiwan [1].

2. Data and Methods

2.1. W Phase Inversion

We refer readers to Kanamori & Rivera [2] regarding theory, modeling, and source inversion of *W* phase. We sorted out earthquakes from the GCMT catalog ([3], [4]) that occurred between January 2000 and July 2011, were bounded by 22°N/35°N and 120°E/134°E, and had moments greater than 10^{25} dyn-cm, (Fig. 2). The three component (ZNE) LH channel data (1 sample-per-second) were collected through Web site for *W* phase source inversions. We tested for six scenarios of two groups: group I using vertical component only and group II using all three ZNE components. In each group, three scenarios are tried with different level of knowledge on earthquake parameters: (1) using the GCMT centroid parameters (impractical in real events), (2) using the hypocenter parameters (lon., lat., depth, origin time) reported by the PDE catalogue, and a centroid time, t_d, determined by grid search; the source half duration, t_h, is set equal to t_d, (3) the same as (2) except the centroid location (lon., lat.) determined by a 2-dimensional grid search (depth fixed at PDE's). We indicate the three scenarios as gCMT location, t_d location, and [t_d+xy] location, respectively. An example of final fitting between synthetic and observed waveforms of vertical component for the first shock of the 20090805 earthquake is shown (Fig. 3). The frequency band used to filter seismic waveforms basically follows Table 1 of Hayes *et al*. [5] except that for a few M_w～6.0 earthquakes, the band is fine-tuned to have better results.

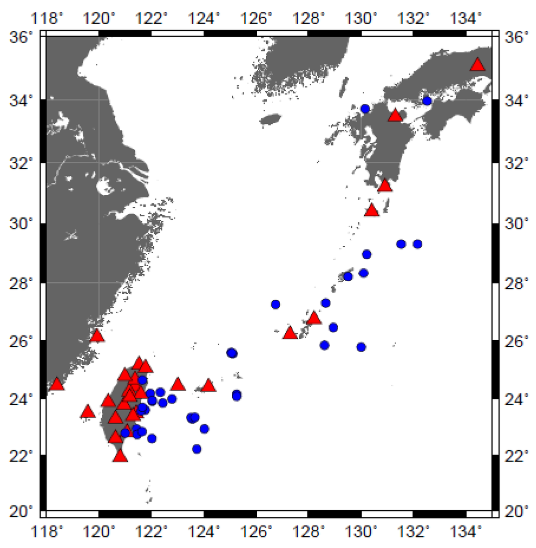

Fig. 2. Distributions of earthquakes (circles) associated with the Ryukyu subduction zone for *W* phase inversion. Red triangles are stations where data are collected.

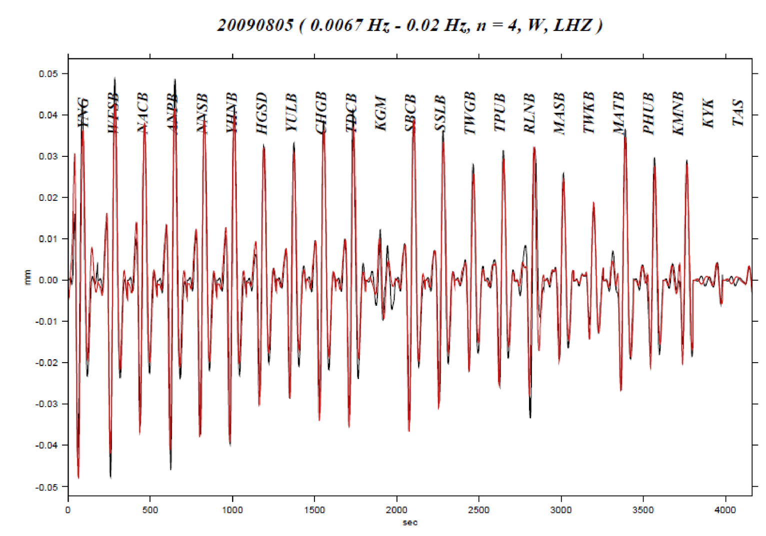

Fig. 3. Observed (black) and synthetic (red) *W* phase for the first shock of the 20090805 earthquake. The *W* phase time window of each station is trimmed and concatenated for inversion. Labels are names of stations.

2.2. Unit Tsunami Methods

The unit tsunami methods pre-calculate propagation of unit sources with the resulting unit tsunamis stored in database for synthetics of real tsunami waves. The principle of unit tsunami methods is conceptually analogous to Green's function in Seismology and only works in linear systems. As compliance, we aim at predicting the offshore – prior to the run-up stage - arrival times and amplitudes of approaching tsunami waves, where the governed equations are the linear shallow water wave equations. The potential source region of the Manila subduction zone was divided into 14x10 square pixels, each with 1.0°x1.0°in size and an initial vertical seafloor displacement of 1 m was assigned to each pixel to constitute the group of unit sources (Fig. 4). We employed Cornell Multigrid Coupled Tsunami Model (COMCOT; [6]) to simulate the propagations of each unit source. We set up 32 virtual stations representing existing tidal stations of Central Weather Bureau (Fig. 5). The wave field of one station from one unit source is referred to the unit tsunami corresponding to the station-unit source pair and the unit tsunamis for the 32 stations were stored in database. In the end, a total of 14x10x32 unit tsunamis were stored in database for synthetics of tsunami waves in real events. The stored unit tsunamis are readily available for arrival time predictions even without the occurrence of real events. We applied Short Time Average over Long Time average (STA/LTA; [7]), a conventional scheme for picking seismic P and S phases, to automatically pick the arrival times of unit tsunamis with results stored in database for arrival time predictions.

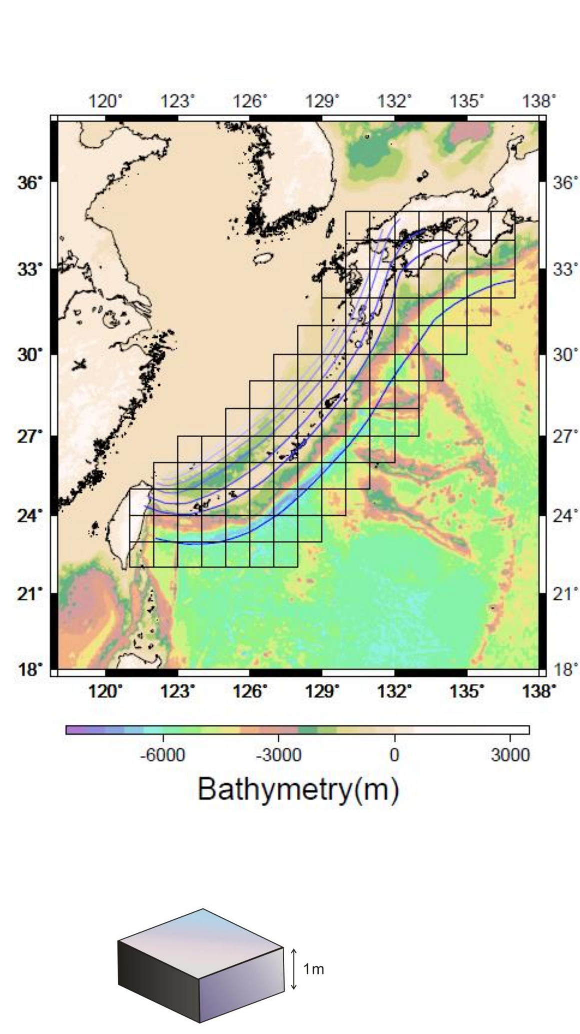

Fig. 4. (Top) Division of the Ryukyu subduction zone into 107 pixels of unit sources. (Bottom) The one-meter initial vertical displacement assigned as unit source.

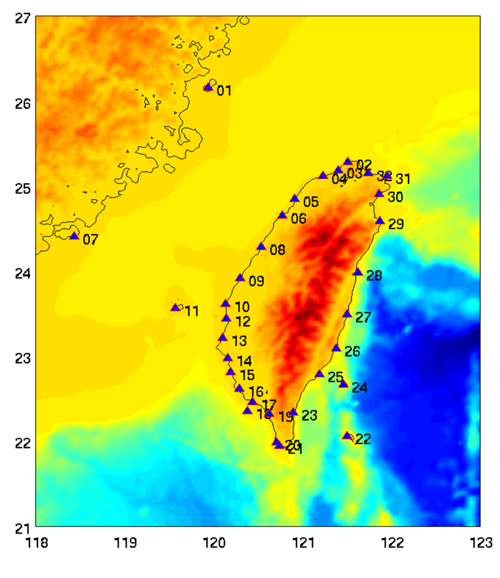

Fig. 5. Locations of 32 CWB tidal stations where we set up virtual stations to record unit tsunamis of the 14x10 unit sources. The stations are numbered from north to south in a counterclockwise sense surrounding Taiwan.

3. Results

3.1. W phase inversion

We judge the qualities of solutions based on the discrepancies between those of *W* phase inversion and those of GCMT solutions of the same event, in terms of both moment magnitudes (M_w) and focal mechanisms. The comparisons of M_w for six scenarios are presented in Fig. 6 with group I (Z component only) in the first column and group II (ZNE components) in the second column. The numbers in each box (scenario) indicate the absolute means of magnitude differences and corresponding standard deviations. The absolute means of all six scenarios are less than 0.1 unit, validating the application of *W* phase inversion using data of regional network to determine source parameters of Ryukyu trench earthquakes greater than M_w5.9. Among the three tried scenarios (gCMT location, t_d location, and [t_d+xy] location), only the last two are practicable in real-time *W* phase inversion, among which the group II t_d location is the best scenario (least discrepancies). The Kagan rotation angle refers to the solid angle rotating from one double couple to another [8] and thus is a measurement of focal mechanism discrepancies. We present the Kagan angles - relative to the GCMT solutions of the same events - of the six scenarios in Figure 7 ith mean and standard deviation indicated, using the same fashion as Figure 6 Again, the group II t_d location is the one with the minimum mean among all real-time practicable scenarios.

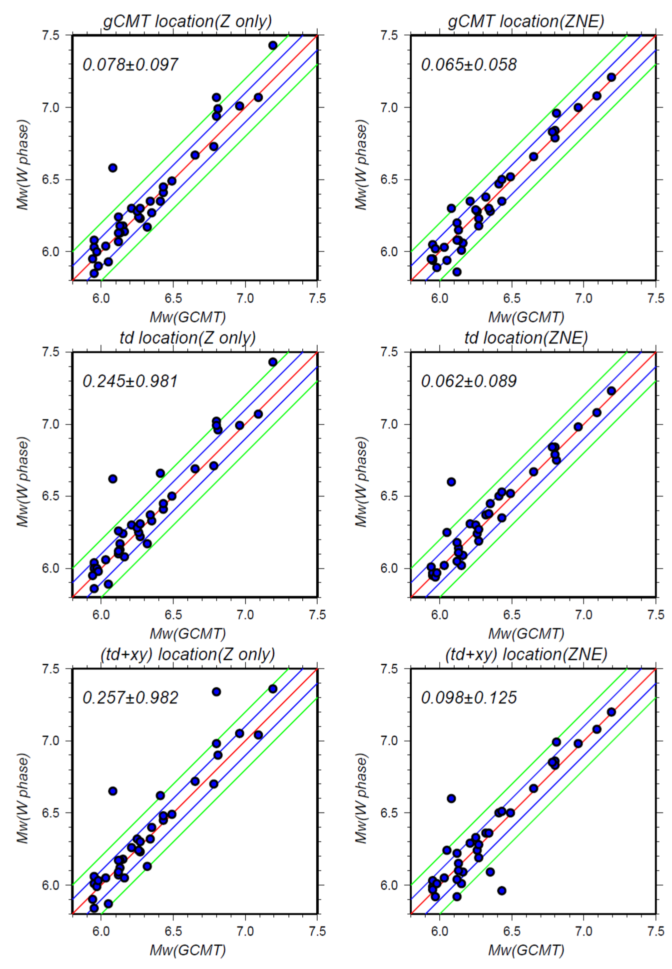

Fig. 6. Comparison of M_w (GCMT) and M_w (*W* phase) for earthquakes used in this study with blue for near group and green for far group. The left column is results of Z component only (group I) and the right one ZNE components (group II). Top to bottom represents three sets of scenario for different level of knowledge on earthquake parameters (see text). Numbers are mean values for differential M_w and standard deviation. The best result is those of group I GCMT location (top left) and the best one among practicable scenarios is group II t_d location.

3.2. Unit tsunamis

Characteristics of tsunami wave propagation in the Ryukyu trench and around Taiwan depend on bathymetric features and can be learned from simulated propagation of unit sources. Fig. 7 shows the propagation waves at different time frames of an exemplary unit source. Fig. 8 shows the resulting 32 unit tsunamis of the exemplary unit source, which demonstrate that stations 26 to 31 on east coasts of Taiwan are the most affected ones (Fig. 5). The STA/LTA scheme works well in determining the arrival times of unit tsunamis (Fig. 9) and we compile the data to produce one arrival-time map for each unit source (Fig. 10), which will also be stored in database and are readily for prompt arrival-time predictions.

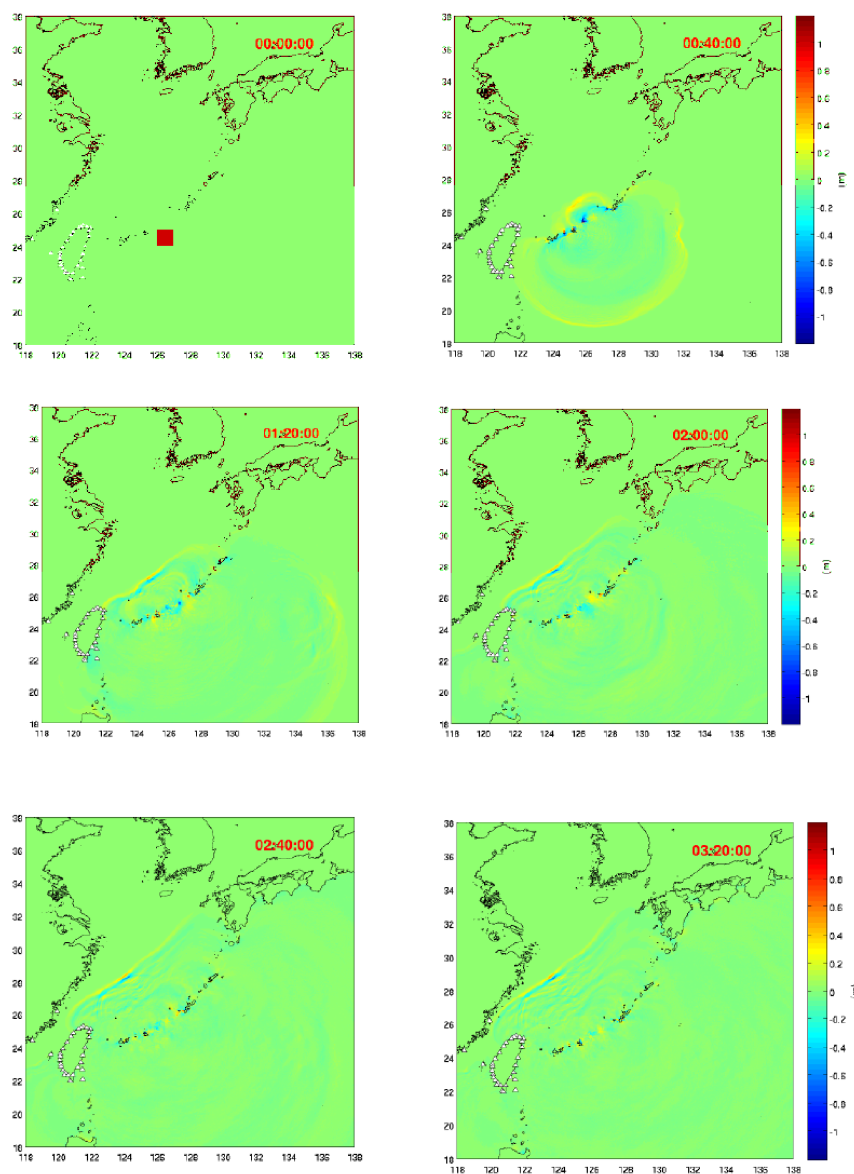

Fig. 7. Propagation of tsunami waves of an exemplary unit source. The triangles surrounding Taiwan are the existing CWB tidal stations where we set up virtual stations to record the unit tsunamis. Top left: location of the unit source. Top right: after 40 min., note that the wave has reached Hualien on east Taiwan coast. Middle left: after 80 min., the tsunami wave along eastern Taiwan has reached the majority of north Taiwan. Middle right: after two hours, west coasts of Taiwan start to be affected by the tsunamis. Bottom left: after 160 min., almost all Taiwan coasts have been attacked by tsunamis. Bottom right: after three hours and 20 min.

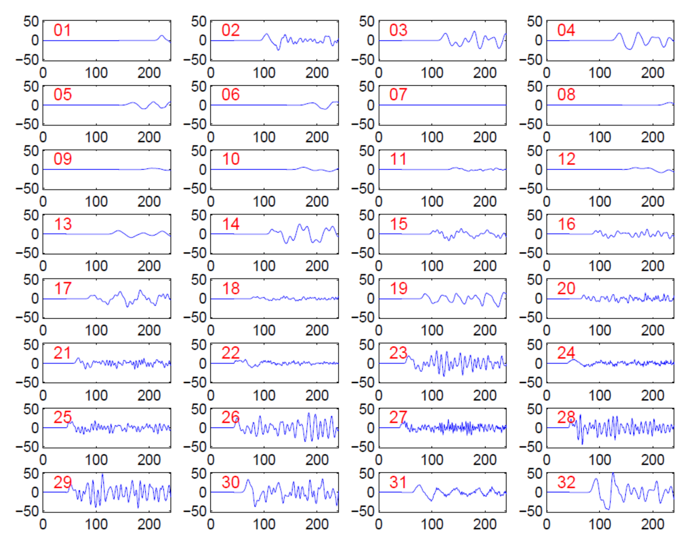

Fig. 8. Unit tsunamis of the 32 virtual stations for the unit source in Fig. 3. Red numbers indicate stations following Fig. 5. Unit is minute for *x*-axis and cm for *y*-axis.

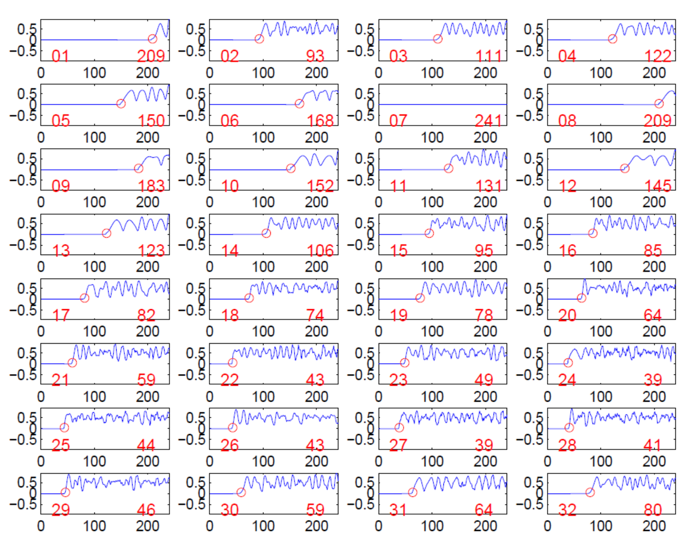

Fig. 9. Results of STA/LTA scheme applying on the unit tsunamis. Note the sharp arrivals of tsunami waves make their picking robust. Unit is minute for *x*-axis and STA/LTA ratio for *y*-axis. The numbers to the right of each box is the picking arrival-time in minute.

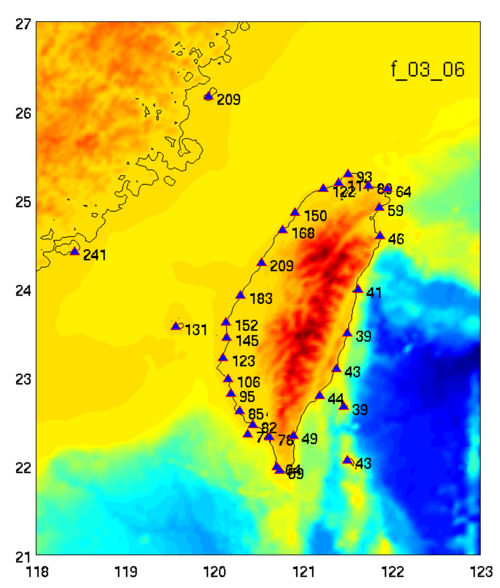

Fig. 10. The arrival time maps for the exemplary unit source in minutes.

5. Conclusions

In this study, we propose to combine *W* phase inversion and unit tsunami methods to build a tsunami warning system in Taiwan for earthquakes in the Ryukyu subduction zone region. The *W* phase inversion allows us to rapidly determine moment tensors of large earthquakes for the calculations of vertical seafloor displacements. The applicability of *W* phase inversion for Ryukyu earthquakes using BATS and F-net stations has been attested. We have built a database of unit tsunamis for the source region of the Ryukyu subduction zone and the prediction of arrival times is readily available once the epicenter of tsunamigenic earthquake is known.

References

[1] Soloviev S.L., Go Ch.N. Nauka Publishing House, Moscow, USSR, 310 pp., 1974. Can. Transl. Fish. Aquat. Sci. 5077, 1984.
[2] Kanamori H., Rivera L. Geophys. J. Int. 2008 ; 175 : 222-238 doi: 10.1111/j.1365-246X.2008.03887.x
[3] Dziewonski A. M., Chou T.-A., Woodhouse J.H. J. Geophys. Res. 1981; 86: 2825-2852.
[4] Ekström G., Dziewonski A.M., Maternovskaya N.N., Nettles M. Phys. Earth planet. Inter. 2005; 148(1-2): 327-351.
[5] Hayes G.P., Rivera L., Kanamori H. Seismological Research Letters. 2009; 80(5): 817-822 doi: 10.1785/gssrl.80.5.817
[6] Liu P.L.-F., Woo S.-B., Cho Y.-S. Technical Report, Cornell University; 1998.
[7] Allen, R. Bull. Seismol. Soc. Am. 1982; 72(6): 225-242.
[8] Kagan, Y.Y. Geophys. J. Int. 1991; 106(3): 709-716.