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学位論文題目	Elucidation of seafloor crustal movements off northeastern Japan by GPS/acoustic technique with evaluation of sailing observation data from hull-mounted system (GPS/音響測距結合方式の海底地殻変動観測における航走観測データの評価と東北日本沖の海底地殻変動の解明)
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論 文 内 容 要 旨

The Hydrographic and Oceanographic Department of Japan (JHOD) has been developing a system for precise seafloor geodetic observation with the GPS/acoustic combination technique since 1990s and deployed seafloor reference points on the landward slope of the major trenches around Japan, such as the Japan Trench and the Nankai Trough, starting with having installed four acoustic transponders on the seafloor of Kumano nada in 2000. Since then, the JHOD has been carrying out campaign observations using a survey vessel, while improving the technique in aspects of observation and analysis. In particular, observation efficiency has dramatically improved through the introduction of a new hull-mounted system in 2008, which had made possible the ranging measurements with the vessel sailing, instead of the drifting, uncontrollable way as before.

In this thesis, as well as evaluating sailing observation data acquired with the new hull-mounted system, we discuss interplate coupling off northeastern Japan, based on seafloor geodetic observation data accumulated for about nine years before the 2011 Tohoku-oki earthquake (M9.0). We also present the huge co-seismic displacements associated with the 2011 event, observed in the region.

First, we have introduced the establishment of the sailing observation with the hull system and evaluated the positioning results from the sailing observation by using data acquired for about three years.

Comparison between campaign solutions of the sailing and drifting observation revealed that no significant offsets beyond the level of the positioning precision before the system transition is found, which ensures the continuity of the positioning results due to the transition of the onboard system.

We have also evaluated the repeatability of campaign solutions of the sailing observation by utilizing linear fitting to the time series of campaign solutions at all seafloor reference points. The repeatability for the sailing observation is about 2 cm in root mean squares in the horizontal component, which is better than that for the early drifting observation. Moreover, the stability of subset solutions estimated from a part of data and relative position determinations among four seafloor stations has also been improved by the introduction of the sailing observation. Comparison between different sea regions suggests that the positioning precision is better at the seafloor reference points along the Nankai Trough than those along the Japan Trench.

Furthermore, the precision of height determination has also been improved, though it is still inferior to that of horizontal positioning. It is expected that vertical crustal movement will be detectable in the future through accumulation of observation data as well as further technology development.

Next, we have presented seafloor geodetic observation results conducted for about nine years in the sea region off northeastern Japan, especially the sea area off Miyagi Prefecture, and have discussed the spatio-temporal change of interplate coupling.

Off Miyagi Prefecture, a series of seafloor crustal movements indicating strain accumulation-release process have been observed. Until the 2005 off-Miyagi earthquake (M7.2), the seafloor off Miyagi Prefecture had been moving west-northwestward at a rate of 6-7 cm/year relative to the North American plate, indicating strong interplate coupling resulting in strain accumulation. In this course, the 2005 event generated eastward co-seismic movements of about 9 cm at the seafloor reference point MYGW and about 3 cm at the seafloor reference point MYGI, located about 10 km and 60 km east of the epicenter, respectively. These movements exhibit strain release process by the upper plate rebound caused by the event. Thereafter, the seafloor in this region started to move again westward since around 2007 after the period of the post-seismic deformation for 1-2 years, which indicates the restoration of interplate coupling.

The crustal velocity since December 2006 is 4-5 cm/year relative to the North American plate, which is significantly smaller than that before the 2005 event. Therefore, it is indicated that interplate coupling off Miyagi Prefecture since around 2007 is weaker than that before the 2005 event. This is consistent with the results from GPS data since 2007.

On the other hand, the seafloor at the seafloor reference point off Fukushima Prefecture, labeled FUKU, had been moving westward at a constant rate of about 2 cm/year relative to the North American plate from 2002 to 2008. After that, interplate coupling around FUKU was weakened by the post-seismic slip subsequent to the Off-Fukushima earthquake (M6.9) on July 19, 2008. As a whole, interplate coupling during an interseismic period in this region is significantly weak compared with that off Miyagi Prefecture.

Finally, we have reported the co-seismic displacements associated with the 2011 Tohoku-oki earthquake (M9.0), which occurred on the plate boundary off Miyagi Prefecture on March 11, 2011. Comparison between the positions before and after the 2011 event has exhibited huge co-seismic displacements associated with the event in the focal region; the largest amount reaches 24 m east-southeastward and 3 m uplift at MYGI just above the hypocenter, which is more than 4 times larger than those detected on land. Other than MYGI, the co-seismic displacements of 15-23 m off Miyagi Prefecture and 5 m off Fukushima Prefecture have also been detected. These results indicate that the area where co-seismic displacement is greater than 20 m extends at least 70 km toward north-northeast from the epicenter.

From our seafloor observation results together with various studies on co-seismic slip distribution, we can conclude that the co-seismic slip caused by the mainshock occurred mainly close to the trench axis northeast of the hypocenter and the maximum slip was more than 50 m. In addition, in the vertical displacement, opposite polarity has been observed at MYGI and MYGW, aligned in a direction perpendicular to the trench axis, which suggests that the hinge line corresponding to null displacement is located on the east side of MYGW.

We should emphasize here that the realization of sailing observation by the transition to the hull-mounted system has brought great efficiency to our observations and enabled us to catch the unprecedented displacements even in the short-time observation after the 2011 event.

Seafloor crustal movements obtained in this study have clearly demonstrated indispensible roles of seafloor geodesy. Continuous observations with further development of the technology as well as the infrastructure are essential for detailed understanding of interplate earthquakes which occur in the sea region.

論文審査の結果の要旨

本論文は、GPS /音響測距結合方式による海底地殻変動観測に関して、海上保安庁の船底装備システムによる新たな航走観測手法の精度評価を行うとともに、2011年東北地方太平洋沖地震までの約9年間の海底地殻変動データに基づき、同地震前の東北日本沖のプレート間の固着状態の時空間変化を明らかにし、同地震に伴う海底変位についての議論を行ったものである。

航走観測手法の精度評価については、従来の漂流観測手法との違い、海域による違い、観測データ量の違いによる3つの観点から定量的に精度評価を行い、航走観測手法の測位精度を明らかにした。その結果、同手法による繰り返し精度は約2 cmで、日本海溝沿いよりも南海トラフ沿いの方が測位精度の高いことが示された。さらに、上下変動成分の精度にも大幅な改善が見られており、上下変動の検出可能性が示めされた。

次に、東北地方太平洋沖地震前の海底地殻変動については、太平洋プレートの沈み込みに伴う歪みの蓄積－解放サイクルを海底の動きとして検出することに成功した。宮城沖では2007年以降は2002～2005年に比べてプレート間の固着が弱いこと、福島沖では宮城沖に比べて固着が弱いことを示し、両地域における固着度合いの時空間的な違いが明らかとなった。

東北地方太平洋沖地震に伴う海底変位については、地震後の臨時観測から震源域直上における地震時変位を広域で検出し、宮城沖で15～24 m、福島沖で約5 mの水平変位が生じたことを明らかにした。さらに、海溝軸直交方向の上下変位から、地震による陸側プレートの跳ね上がりを示唆するような海底の隆起及び沈降を検出した。これらの結果は、海溝付近で50 mを超える地震時すべりがあったことを裏付ける貴重な観測データとなった。

本論文で得られた海底地殻変動は、プレート境界地震の歪みの蓄積－解放サイクルを理解する上で、陸上のGPS観測網だけでは知りえない貴重な情報を有しており、海底測地観測の重要性を改めて実証したものである。

以上のように本論文は、GPS /音響測距結合方式による海底地殻変動観測に関して、観測結果を検証し、新たな観測手法による精度評価を行うとともに、観測に基づく新しい多くの知見を得ており、本人が自立して研究活動を行うのに必要な高度の研究能力と学識を有することを示している。したがって、佐藤まりこ提出の博士論文は、博士（理学）の学位論文として合格と認める。