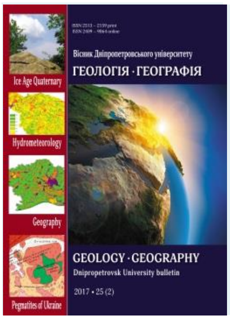


Geology • Geography
Dnipro university bulletin

Journal home page: geology-dnu-dp.ua

ISSN 2313-2159 (print)
ISSN 2409-9864(online)

Dniprop. Univer.bulletin.
Geology, geography.,
25(2), 117-122.

doi: 10.15421/111726

Attempt to Create a Cartographic Forecast Model of Subsidence Degradation for the Right Bank Area of the City Dnipro

T.P. Mokritskaya, K.A. Samoylych

Oles Honchar Dnipro National University, Dnipro, Ukraine, e-mail:mokritska@i.ua

Received 12 October 2017
Received in revised form 28 October 2017
Accepted 10 November 2017

Abstract. Modeling of geodynamic risk is a highly relevant scientific issue; its solution requires solving particular problems in creating a model of the geological environment, selecting the risk factors, creating a model of process, acknowledging the scenarios and prognoses. Geodynamic risk in the areas of development of subsident soils can be defined as the possibility of massif deformations during changes in the soil condition (degradation). The limit state is the state of full water saturation, when the possibility of subsidence is low. Application of the three-term gradation to the scale of conditions sets the boundary values of soil moisture – the indicators of mild, average and critical changes. The predicted condition of the massif is set by a system of features – independent variables, input parameters correlated with values of moisture and values of degradation of subsidence properties. The predicted value of subsidence degradation under additional loading and in natural conditions is found using the group method of data handling. Widespread presence of subaerial loess-like formation in the composition of the geological environment in stratigraphic-genetic complexes of different composition and properties, and in water-bearing horizons, leads to intense development of exogenous geological processes and vulnerability of the environment.

Typification of the geological structure of the massif was performed using the results of analysis of numerous engineering-geological studies (Dnipro, 1960-2007). The total number of wells is 785, the depth varies from 15 to 56 m. The mapping of surfaces of particular horizons, terrain, thickness of aeration zone was developed using a "Surfer" demo-version. Interpolation was made using the Kriege method. Development of models of surfaces of the top of and thickness of horizons and took the erosional washout into consideration. The analysis of cartographic material shows that loess and paleosol horizons have different consistencies.

The following processes were modeled: the change in the condition in relation to moisture of the subsident soil massif within the zone of low-intensive aeration, the value of additional pressure equals 0.3 MPa; the change in the condition in relation to moisture of the subsident soil massif within the zone of averagely intensive aeration, the value of additional pressure equals 0.3 MPa (Fig. 5 b). The results of the prognosis indicate the importance of predicting the subsidence degradation as a factor of geodynamic risk, maximum values reach 0.24 m. Comparing this value to the value of acceptable settling of constructions may suggest the practicability of introducing the method of predicting subsidence to the practice of engineering-geological studies and planning.

Keywords: catastrophic model, degradation, risk.

Опыт создания прогнозных картографических моделей деградации просадочности на примере правобережной части г. Днипро.

Т.П. Мокрицкая, К.А. Самойлич

Днепровский национальный университет имени Олеся Гончара, Днепр, Украина, e-mail: mokritska@i.ua

Резюме. Моделирование геодинамического риска – актуальная научная проблема, решение которой предполагает решение отдельных задач по созданию модели геологической среды, выбору факторов риска, создания модели процесса, обоснования сценариев и прогноза. Геодинамический риск в районах развития просадочных грунтов может быть определен как вероятность деформаций массива при изменении состояния грунтов (деградации). Предельным является состояние полного водонасыщения, при котором вероятность просадочности мала. Применив трехчленную градацию к шкале состояний, можно задать граничные значения влажности грунта – индикаторы умеренных, средних и критических изменений. Прогнозное состояние массива задается системой признаков – независимыми переменными, входными параметрами, коррелирующими со значениями влажности и значениями деградации просадочных свойств. Прогнозное значение деградации просадочности при дополнительных нагрузках и в природных условиях определяется методом группового учета аргументов. Повсеместное присутствие в составе геологической среды субаэральной лессовидной формации, залегающей на стратиграфо-генетических комплексах различного состава и свойств, присутствие водоносных горизонтов, приводят к активному развитию экзогенных геологических процессов, уязвимости среды.

Типизация геологического строения массива выполнена по результатам.обработки многочисленных материалов инженерно-геологических исследований (г. Днипро, 1960 - 2007 гг.). Общее количество скважин – 785, глубина изменяется от 15 до 56 м. Построение карт поверхностей отдельных горизонтов, рельефа, мощности зоны аэрации выполнено с привлечением демо-версии ПО "Surfer", интерполяция выполнялась методом Криге. При построении моделей поверхностей кровли горизонтов и мощностей учитывался эрозионный размыв. Анализ картографических моделей показывает, что лессовые и палеопочвенные горизонты обладают различной выдержанностью.

Моделировались следующие события: изменение состояния по влажности массива просадочных грунтов в объеме зоны аэрации слабой интенсивности, величина дополнительного давления 0.3 МПа; состояния по влажности массива просадочных грунтов в объеме зоны аэрации средней интенсивности, величина дополнительного давления 0.3 МПа (Рис. 5 б). Результаты прогноза указывают на важность прогноза деградации просадочности как фактора геодинамического риска, максимальные значения достигают 0,24 м. Сравнивая это значение с величиной допустимых осадок сооружений, можно сделать вывод о целесообразности внедрения методики прогноза деградации просадочности в практику инженерно-геологических исследований и проектирования.

Ключевые слова: картографическая модель, деградация, риск.

Introduction. Developing a spatial model of subsidence is one of the stages in forecasting geodynamic risk during geoecological research. Modeling geodynamical risk is a relevant scientific issue and its solution is significant for the optimum management of a territoriy`s condition, planning measures for protection through engineering. Methodological aspects of calculating and forecasting risk is in many ways related to the object of study. The strategy of risk management is one of the issues which is widely discussed all around the world (Parkash, 2014; Bles et al, 2009; China Earthquake Administration, 2008). Global methodological problems of mapping and integral calculation of geodynamic risk and methods of their solution are analyzed in the article (Osipov et al, 2017). Interrelations between geochemical cyclic natural and technogenic processes (Nuss, Blengini, 2018) are significant for managing risk caused by pollution. Geodynamic risk is related to tectonic and landslide activity (Pospíšil, et al, 2017; Kučeravcová and Dzurdženík, 2016), and surface deformations of a natural and technogenic character in cities (Zhantayeva et al, 2014). Spatial models of distribution of dangerous landslide processes should be based on highly accurate observations (Skrzypczak et al, 2017). It has been proposed that the questions of spatial disintegration of aggregated objects should be solved on the basis of a probabilistic approach (Dong et al, 2017). For providing protection, it is important to study relations between a possible dangerous event and the resources necessary for its liquidation (Robinne et al, 2018). An example of successful spatial modeling of prognosis of wind erosion of soils is the work by Simon Schmidt (Schmidt et al, 2017). The number of problems involved in modeling geodynamic risk includes problems of cartographic modeling of hydrographic parameters (Dong, 2017), problems of modeling the possibility of landslide processes (Tien Bui, 2017). At the same time, due to insufficient accuracy of prognoses of natural and technogenic catastrophes, the use of warning systems such as civil defense sirens , messages in social networks (Nourbakhsh et al, 2017) or dissemination of the results of observations collected by volunteers (Crimmins, 2017) is still strongly advised.

Geodynamic risk in areas of development of subsident soils can be calculated as the possibility of massif deformations caused by change in the soils` condition. The limit state can be set as the state of full water saturation, when the possibility of subsidence is slight. Using three-term gradation in scale of conditions in relation to moisture, the boundary values of the soil moisture can be set – indicators of mild, average and critical changes. The predicted condition is set through a system of features – independent variables correlated with values of moisture and values of subsidence properties` degradation. The predicted value of subsidence degradation in case of additional loading and in natural conditions is calculated with the group method of data handling. This requires studying the impact of change in the ratio of the number of aggregates and particles of different fraction on the values of possible deformations (subsidence). A necessary condition for developing the model is identifying the microaggregate composition of the soil in three ways of preparation.

Development of spatial model of degradation of subsidence properties requires solving the following problems:

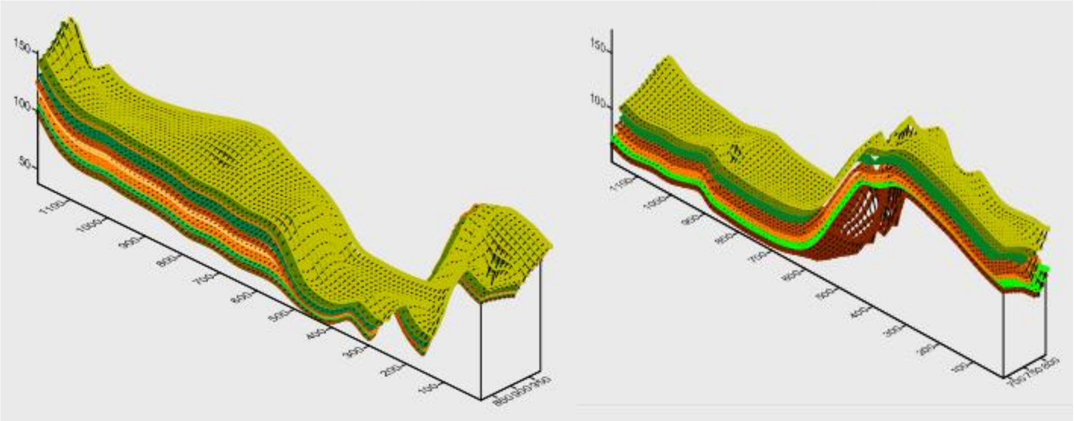
- developing a spatial model of the geological composition of the massif;
- setting the volume of the aeration zone;
- calculating the predicted total values of subsidence degradation of loess-like and paleosol horizons;
- calculating predicted total values of deformations caused by degradation of structure – break up of aggregates when there is increase in moisture in the zone of aeration under natural conditions and in the zone of impact from construction.

Results. The territory of Dnipropetrovsk Oblast partly covers two engineering-geological regions of the IInd order: the Ukrainian Crystalline Shield (UCS) and the Dnieper-Donetsk Depression (Bobrov et al, 2002). The Prydniprovsky Megablock lies within their boundaries. There are extensive Cenozoic deposits. The Paleogene period is represented by the Buchakovska, Kyivska, Obuhovska, Mejihirska and Berekska rock formations. The Miocene section of the the Neogene system is represented by formations of the Novopetrivska rock formation, Sarmatsky regional stage, a layer of spotted clays. The Pliocene section is presented by a layer of reddish-brown clays, which are overlapped by deposits of the Eopleistocene and Pleistocene epochs. The topping of Pliocene reddish-brown clays becomes rare towards the South, and correspondingly the thickness of loess cover in the South-East changes. The loess subzone (within borders of the Prydniprovska right bank broken loess plain) has a wide distribution, and significant thickness (up to 25-35 m). The lower part of the Neopleistocene section includes 6 climatolites: from Shyrokinsky to Tylyhulsky. The compound of subaerial horizons includes the Zavadovsky, Dniprovsky, Kaidaksky (marked) and Tiasmynsky climatolites. The top of the Zavadovsky horizon is observed to show signs of frost shattering. The Dniprovsky climatolite is presented by moraine, and mostly out-glacier deposits. The formations of the Vitachevsky and Butskyclimatoles are overlapped by the unbroken deposits of the Prychornomorsky and Dofinivsky horizons. The alluvial deposits of the first-third terraces (a3PIIItb), (a2PIIIvl), (a1PIIIds) are widely distributed.

The differences in the regional factors of engineering-geological conditions are related to the peculiarities of formation and washout of marine shallow and continental pre-Quaternary deposits, glacier and out-glacier, and alluvial Pleistocene deposits. Having a wide distribution of subaerial loess-like formation bedded on stratigraphic-genetic complexes of different composition and properties, wide distribution of disperse deposits of clayey content, water-bearing horizons with peculiar patterns of formation and regime, the regional geological environment is varied in its engineering-geological conditions, unstable, intense in the development of exogenous geological processes and vulnerable. The typology of the geological content of the massif is made based on the results of analyzing numerous engineering-geological studies (Mokritskaya, 2013). The unified data base on the conditions of loess soils includes materials of research made by the Ukrainian State University of Engineering-technical Research, Dnipro State Road Project-investigation and Scientific-research Institute, Dnipro State Institute for Transport Development, and Design Bureau "Yujukrgeologia" (South Ukrainian Geology). The total number of wells is 785, the depth varies from 15 to 56 m. The data is representative, but the zone of historical constructions – the right bank of the city – is better studied. The wells were put on the map of factual material, the materials of the topographic survey were included on a scale 1:25,000 in 1986 and 1995, and satellite images were taken into account (2008, internet source , the Google Earth programme). Mapping of the surfaces of certain horizons, terrain, and thickness of the aeration zone was conducted using the "Surfer" demo-version, interpolation was performed using Kriege's method. The development of models of horizons` top surfaces took into account the erosional washout in the basins of the following erosional systems: Tonnelna, Vstrechna, Rybatska, Aptekarska, Yevpatoriiska, Krasnopolska and Lotsmanska.

The analysis of the cartographical model indicates that loess and paleosol horizons have different stability. The basin of the Krasnopovstancheska ravine has no Buhsky (vdPIII bg), Udaisky (vd PIII ud) and Vitrachevsky (ed PIII vt) horizons. The central part of the city (Gagarin Avenue) has no Vitachevsky and Udaisky horizons (Fig. 2, a, b).

At the next stage, on the basis of data analysis (2003, Design Bureau "Yujukrgeologia") the map of depths of the ground water level, and the map of the thicknesses depths of the aeration zone on a scale 1: 25000 (Fig. 3) were constructed.



a) b)

Fig. 2. Discontinuity in depth conditions of loess soils. Scale 1:25 000 Conditional signs (for Fig. 2 a, b)

🟩 *Prychornomorsky horizon (vd PIII pc);*

🟩 *Buhsky horizon (vd PIII bg);*

🟨 *Vitachevsky horizon (ed PIII vt);*

🟩 *Udaisky horizon (vd P III ud);*

🟫 *Pryluksky horizon (ed P III pl);*

🟧 *Tiasmynsky horizon (vd PII ts);*

🟧 *Kaydaksky horizon (ed P II kd);*

🟩 *Dniprovsky horizon (vd P II dn);*

🟥 *Zavadovsky horizon (ed P II zv).*

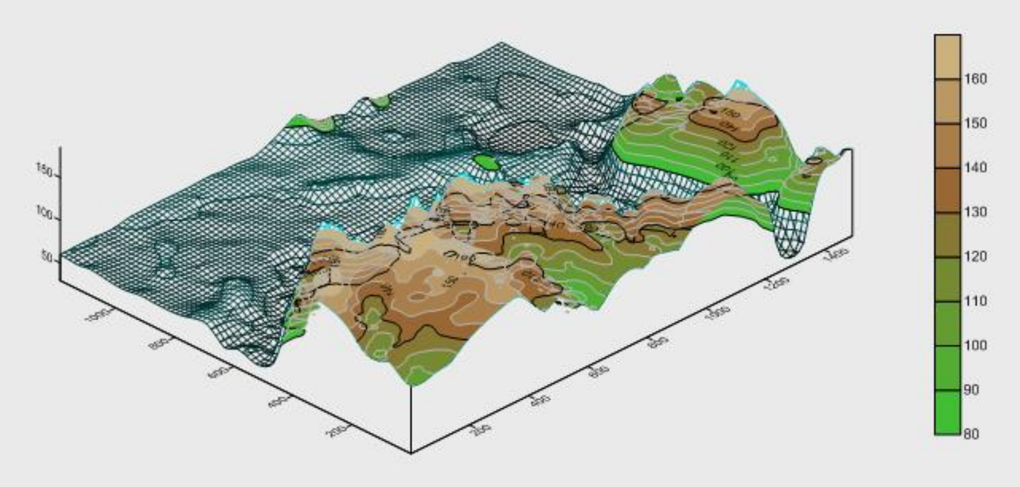


Fig. 3. Conditions of aeration zone depth. Scale 1:25 000

▦ – zone of full water saturation; 🟩🟧 – aeration zone.

On the basis of the results of experiments (Samoilych, Mokritskaya, 2016), we studied the relation between the microstructure and the degradation of the subsidence, developed a mathematical model of degradation of soil subsidence and calculated predicted values of relative subsidence of the horizons.

Predicted values of subsidence degradation of the massif were calculated using the following formula:

$$\Delta S_{SL} = \sum m\varepsilon_{SL}, \qquad (1)$$

m – thickness of the horizon, m;

ε_{sl} – predicted value of subsidence degradation of the horizon in conditions of moistening, loading and evolution of microaggregate composition;

ΔS_{SL} – total value of subsidence degradation of the massif within the area of aeration zone in conditions of moistening and change in microaggregate composition.

The following processes were modeled:

– Change in the conditions in relation to the moisture of the subsident soil massif within the zone of low-intensive aeration, the additional pressure equals 0.3 MPa (Fig. 5 a);

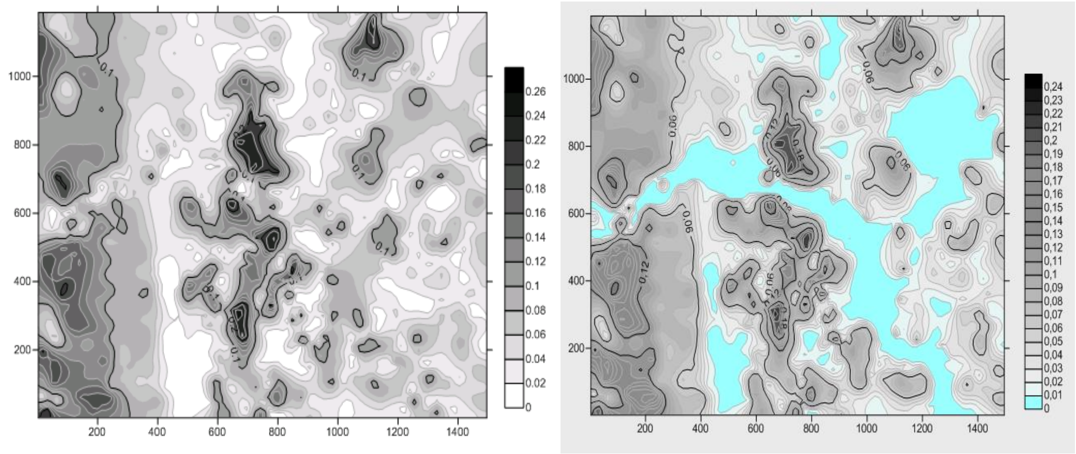
– Moisture conditions of the subsident soil massif within the zone of averagely intensive aeration, the additional pressure equals 0.3 MPa (Fig. 5 b).

The results of the prognosis prove the importance of forecasting the subsidence degradation as a factor of geodynamic risk; highest values reach 0.24 m. Comparing this value to the value of acceptable settling of a construction, we can conclude that the method of forecasting subsidence degradation is useful in the practice of engineering-geological studies and planning.

Conclusions. We developed a cartographic model of the prognosis of degradation of subsidence properties in the zone of impact of the constructions under different variants of disturbance in the conditions of subsident soil massif.

The digital model of subsidence degradation in the massif of loess and loess-like soils is a necessary component of a geodynamic risk model.

The significance of the obtained scientific results lies in the substantiation of the necessity of forecasting geodynamic risk (subsidence degradation) in order to solve the problems involved in planning and rational usage of nature in all its diverse aspects.



a) b)

Fig. 5. Predicted models of geodynamic risk of subsidence degradation in the massif of subsident soils under change in its condition within the aeration zone (1:25 000).

a) model of degradation in the massif under averagely intensive change in its condition;

б) model of degradation in the massif under highly intensive change in its condition.

References

Bles T. J. & M. Th. van Staveren Deltares, P. P. T. Litjens & P. M. C. B. M. Cools. 2009. Geo Risk Scan – Getting grips on geotechnical risks. Geotechnical Risk and Safety Proceedings of the 2nd International Symposium on Geotechnical Safety and Risk (IS-Gifu 2009) Gifu, Japan. doi: 10.1201/9780203867310.ch44

Bobrov O.B., Sivoronov A.O., Malyuk B.I., Lysenko O.M. 2002. Tektonychna budova zelenokamyanykh struktur Ukrayinskoho shchyta. [Tectonic structure of green stone structures of the Ukrainian shield]. Zbirn. Nauk. Prats, UkrDHRI, №1-2, UkrDHRI. 46-67 (in Ukrainian).

China Earthquake Administration. 2008. The M8.0 Wenchuan earthquake seismic intensity map. (In Chinese) Available at:http://www.cea.gov.cn/manage/html/8a8587881632fa5c0116674a018300cf/_content/08_09/01/1220238314350.html

Crimmins T.M., Crimmins M.A., Gerst K.L., Rosemartin A.H., Weltzin J.F. 2017 USA National Phenology Network's volunteer-contributed observations yield predictive models of phenological transitions. PLoS ONE 12(8): e0182919. https://doi.org/10.1371/journal.pone.0182919

Dong T., Harris N. B., Ayranci K., Yang S. 2017. The impact of rock composition on geomechanical properties of a shale formation: Middle and Upper Devonian Horn River Group shale, Northeast British Columbia, Canada. AAPG Bulletin, v. 101, no. 2. 177–204. doi:10.1306/07251615199

Kučeravcová A., Dzurdženík J. 2016. Spatial planning focusing on risk management in Slovakia. Spatial Planning and Resilience Following Disasters, Policy Press. DOI: http://dx.doi.org/10.1332/policypress/9781447323587.003.0008

Mokritskaya T. P. 2013. Formyrovanye y evolyutsyya heolohycheskoy sredi Prydneprovskoho promishlennoho rehyona. [Formation and evolution of geological environment Pridneprovsk industrial region]. Dnipropetrovsk, Accent PP (in Russian).

Nourbakhsh A., LiA., LiuX., ShahS. 2017. "Breaking" Disasters: Predicting and Characterizing the Global News Value of Natural and Man-made Disasters/DATA SCIENCE, JOURNALISM, Halifax, Canada. https://sites.google.com/view/dsandj2017/accepted-papers

Nuss P., Blengini G. A. 2018. Towards better monitoring of technology critical elements in Europe: Coupling of natural and anthropogenic cycles. Science of the Total Environment 613–614. 569–578.DOI: http://dx.doi.org/10.1016/j.scitotenv.2017. 09.117

Osipov V. I., Larionov V. I., Burova V. N., Frolova N. I., Sushche S. P. 2017. Methodology of natural risk assessment in Russia: Nat Hazards 88: S17–S41. DOI: 10.1007/s11069-017-2780-z

Parkash S. 2014. Geohazards Risk Management in India. 8th Asian Rock Mechanics Symposium ARMS8, Sapporo, Japan

Pospíšil L., Švábenský O., Roštínský P., Nováková E., Weigel, J. 2017. Geodynamic risk zone at northern part of the Boskovice Furrow. ActaGeodynamica et Geomaterialia, 14, No. 1 (185), 113–129. DOI: 10.13168/AGG.2016.0033

Robinne F.-N., Bladon K. D., Miller C., Parisien M.-A., Mathieu J., Flannigan M.D. 2018. A spatial evaluation of global wildfire-water risks to human and natural systems. Science of the Total Environment 610–611. 1193–1206. DOI: 0.1016/j.scitotenv.2017.08.112

Samoilych K. O., Mokritskaya T. P. 2016. Change in the parameters the microstructure of loess soil during filtration. Vysnik Dnipropetrovskogo University. Seriya: Geologiya. Geografiya. 24 (2), 106–113. Doi: 10.15421/111638

Schmidt S., Meusburger K., de Figueiredo T., Alewell Ch. 2017. Soil loss by wind (SoLoWind): a new GIS-based model to identify risk areas. DBG Jahrestagung der Deutschen Bodenkundlichen Gesellschaft, At Göttingen.

Skrzypczak I., Kogut J., Kokoszka W., Zientek D. 2017. Monitoring of landslide areas with the use of contemporary methods of measuring and mapping. /Civil and environmental engineering reports. CEER 2017; 24 (1): 069-082. DOI: 10.1515/ceer-2017-0005

Tien Bui D., Ngoc D. A., Bui H.-B. 2017. Science (eds.), Advances and Applications in Geospatial Technology and Earth Resources. DOI: https://doi.org/10.1007/978-3-319-68240-2_141

Zhantayeva Z., Kurmanovb B., Bibosynovb A., Fremdb A., Ivanchukova A. 2014. Persistent Scatterers Interferometry technique for urban subsidence monitoring in Kazakhstan Republic. CENTER-IS. Procedia Technology 16. 583 – 587. doi: 10.1016/j.protcy.2014.10.006