Send Orders for Reprints to reprints@benthamscience.ae

The Open Civil Engineering Journal, 2015, *9*, 805-810

Open Access

The Application of Tunnel Reflection Tomography in Tunnel Geological Advanced Prediction Based on Regression Analysis

Jun Li[1,*] and Zong-lin Wang[2]

[1]*Transportation Science and Engineering College of Harbin Institute of Technology, 150090, Harbin; China;* [2]*The Heilongjiang Institute of Technology of Profession of Building Construction Engineering Institute of Technology, 150050, Harbin China*

Abstract: In the tunnel construction, due to the limitation of the survey and design and the complex dynamics of tunnel surrounding rock geological conditions, so it is difficult for complex geology with the microscopic accurate grasp, often which caused by geological exploration data do not tally with the actual situation, often encountered in karst water inrush, large deformation in weak rock, cave-in subsidence, geological hazards, such as gas outburst, rock burst cause person casualties, delays, in order to minimize geological disaster influence degree, advanced geological prediction before construction is very necessary. Using regression analysis, based on engineering vault subsidence and horizontal convergence has carried on the regression analysis, research results can be reference for related engineering design and construction. Detailed introduces the principle, methods and outstanding characteristic of tunnel reflection tomography advanced prediction system, and take Jianfengling mountain tunnel of Darui line railway as an example, the prediction results are analyzed in detailed processing, and on-site validation, finally points out the problem for further study the technology.

Keywords: Fault fracture zone, geological advanced prediction, tunnel construction, tunnel reflection tomography.

1. INTRODUCTION

In tunnel construction, geological advanced prediction is to use a certain technology and method of tunnel rock mass to collect relevant data, and use the corresponding theory and the law to analyze these data, the research, thus the construction constraints in front of the rock mass condition or forecast hazard possibility. In recent years, along with the in-depth development of the western development strategy and national infrastructure further investment, stimulating domestic demand in complex terrain, landform and geological background, water and mineral resources, the density of road network is far lower than the national average level of the western region, in railway, highway, water and electricity, inter-basin water transfer and mineral resources in areas such as tunnel project will build more grew up. Due to tunnel construction geological condition is very complex, these regions by the geological survey precision, funds and other constraints, according to the geological survey data to design does not accord with the actual situation occurred frequently, especially between the bad geological location accurate position inevitably exist error, the local area often appear in the process of tunnel excavation in karst water inrush, large deformation in weak rock, landslides, subsidence, rock burst, gas outburst and other geological disasters, cause person casualties, delays, and cause huge economic losses, in order to avoid and reduce the possible geological disaster in underground engineering construction, safety, high quality and fast construction of the tunnel, so advance geological forecast must be carried out [1-7]. Forecast constraints in front of the adverse geological location, occurrence, type and the structural integrity of the surrounding rock and the possibility of water, so as to provide the basis for the tunnel construction unit optimizing construction scheme, to prevent outburst tunnel water inrush, sudden mud, gas, etc. May form of severe accidents in a timely manner to provide information, make the engineering unit construction preparation in advance; Constraints can be understand by forecast engineering geological conditions and short distance in front of the rock type, correct selection of excavation section for the construction unit, which provides the basis for supporting design parameters and construction methods.

Tunnel geological advanced prediction has a long history, advanced forecast method of tunnel geological advanced prediction system, horizontal sonic profiles, land sonar method, ground penetrating radar method, advanced drilling method, seismic tomographic advance warning technology and the advanced method of guide to wait for a few kinds. Tunnel Reflection tomography technology (TRT) is the salient feature of the way of observation to achieve the three dimensional space observation, high degree of automation of machine, the software is simple to use and may not need explosive to generate the seismic signal, with a relatively low cost, compared with other advanced prediction method of TRT interface localization, the wave velocity of rock mass and its classification and so on has the high accuracy and can detect the tunnel working face in front of different geological conditions, such as unusual rock mass and empty, and oblique tunnel fracture can reflect well, Especially for solving the problem of water, advanced prediction of broken rock structure, have very good effect in recent years, more and more used in the geological advanced prediction[8-14].

1874-1495/15 2015 Bentham Open

2. REGRESSION ANALYSIS

For a given a set of data (x_i, y_i) (i = 0, 1,…, n), we can find a function y = f (x) to be able to express the relationship between two variables y_i and x_i, then the curve regression line. Measured data scatter generally will not fall on the curve, to make the choice function y = f (x) and the actual scatter difference minimum, the most representative, to use least square method to distinguish.

The Principle of least square method is: given a certain number of data series (x_i, y_i) (i = 0, 1,..., n), if the independent variable x to take a x_i, the corresponding measured values is y_i, return a value is y'_i, and when $M = \sum_{i=1}^{n}(yi - y'i)^2$ takes the minimum sum, the regression line is the best. Usually, monadic linear regression analysis assumes that the function is $y' = a + b \times x'$, when $M = \sum_{i=1}^{n}(yi - a - b \times x_i)^2$ takes the minimum sum,

$\frac{\partial M}{\partial a} = 0, \frac{\partial M}{\partial b} = 0$, thus,

$$b = \frac{\sum_{i=1}^{n}(x_i - \frac{1}{n}\sum_{i=1}^{n} x_i)(y_i - \frac{1}{n}\sum_{i=1}^{n} y_i)}{\sum_{i=1}^{n}(x_i - \frac{1}{n}\sum_{i=1}^{n} x_i)^2} \quad (1)$$

$$a = \frac{1}{n}\sum_{i=1}^{n} y_i - b \times \frac{1}{n}\sum_{i=1}^{n} x_i \quad (2)$$

As a general rule, Headroom tunnel convergence and vault sink accumulative total value does regression analysis with exponential function, and use the function $y = a \times e^{-b/x}$, by the following transformation into a linear regression formula form $y' = a + b \times x'$, which is convenient to determine a and b.

$$y' = \ln y, x' = \frac{1}{x} \quad (3)$$

$$a' = \ln a, b' = -b \quad (4)$$

3. TRT6000 SYSTEM OF GEOLOGICAL ADVANCED PREDICTION

TRT is developed in recent years by the NSA engineering company, currently starts application in Europe, Asia, including Japan, Australia and Hong Kong, which is one of the most advanced scientific and technological achievements in this field at home and abroad, is a kind of geophysical exploration methods. In the crystalline rock mass detection range can be 100-150m, the weak soil layer and broken rock mass can also forecast 60-90 m.

3.1. Prediction Principle

TRT6000 uses the method of seismic wave advanced prediction, whose basic principle is the use of seismic waves in inhomogeneous geological body of sexual reflex potter to predict tunnel excavation near the front side and the surrounding area geology condition. The system transmits signal through the " The Hammer", seismic wave in the rock mass in the form of a spherical spread to all around, the local seismic rock physical interface (namely interface wave impedance difference, such as fault plane, rock fracture zone and lithological change interface, etc.), one part of the seismic signal is reflected (Fig. **1**), another part of the signal refracts into the front. Reflection seismic geophone receiving signal is high sensitivity, the sensor signal through "wireless sensor base station" storage in a computer, obtain seismic signals and data.

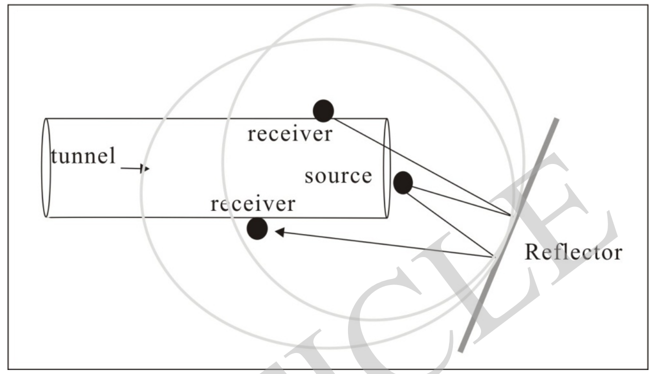

Fig. (1). Principle of TRT exploration.

In simple cases, the seismic reflection wave amplitude is associated with the reflection coefficient of reflection interface, when the plane simple harmonic perpendicular incident to the reflecting surface, the wave reflection coefficient and transmission coefficient are:

$$\frac{A_r}{A_i} = \frac{\rho_2 v_2 - \rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1} = R \quad (5)$$

$$\frac{A_t}{A_i} = \frac{2\rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1} = 1 - R \quad (6)$$

In this equation, A_i is the incident wave amplitude; A_r, and A_t are reflected wave and transmission wave amplitude; v_1, v_2 are reflection interface on both sides of the medium speed; ρ_1, ρ_2 are reflection interface on both sides of the medium density; R is the reflection coefficient of the interface. When the incident wave amplitude Ai must be reflected wave amplitude A_r is proportional to the reflection coefficient R, and the reflection coefficient and reflection on both sides of the medium wave impedance interface ρ v related, and mainly determined by the interface on both sides of the medium wave impedance difference, the greater the absolute value of wave impedance difference, the greater the reflection wave amplitude Ar. When wave impedance of medium Ⅱis greater than medium Ⅰ, wave impedance is relatively dense seismic waves spread from relatively loose medium to medium, the reflection coefficient R > 0 at this point, the reflected wave amplitude and the incident wave amplitude of symbols are the same, reflection wave and the incident wave with the same polarity; On the other hand, if the seismic waves spread from a more dense medium to a relatively loose medium, the reflection coefficient R < 0, the reflected wave amplitude and the incident wave amplitude symbol instead, so the polarity of the reflected wave and the incident wave is on the contrary, the size of the reflector, the greater the difference of acoustic impedance, the greater the echo becomes more obvious, the more likely it is to clearly determine geological liquid property changes.

3.2. The Technical Performance of System

TRT6000 detection system mainly consists of two parts: the instrument system and software system. Instrument system mainly includes: (1) the industrial-grade portable computer; (2) record unit: receiver port 9; Record channel 24; Sampling interval for; Bandwidth for; Record length of 16000 hits per channel; Frequency range: (3) with a wireless module of geophone group: delay for, every millisecond regulation; Working voltage is dc 12 v; Working environment temperature 0-70°. Software system uses Winxp as software platform, processing and evaluation software is highly intelligent, its data processing mainly includes: download the coordinates of the seismic data and the source and sensor position; Set of strata imaging area and the size of the best precision (node number); Set filter, select each record of the direct wave, and calculate the average wave velocity of seismic wave; For the district piece of constructing seismic wave velocity model; Set filter parameters for data processing; Repeat the above steps to deal with the data until the processing result in balance, noise attenuation into a small enough; Set background 2 (proportion, color code) to display the results; review and analysis in the rocks to detect abnormal plane (2D) and three-dimensional (3D) drawing. The system has realized from the information collection, data processing and interpretation of the results highly intelligent. It has a wide range of practical, deciphering of detection, distance, the advantage of high resolution, and implements the three dimensional space observation.

3.3. The Arrangement of Survey Line and Station

TRT6000 technology uses single-point excitation, 10 sensor receiving are installed in three dimensional space, achieve the three-dimensional space observation. In the distance a focal point for 10m began to decorate sensors, each wall four, every 5m (range direction) a, the center line of the tunnel vault at 2. The coupling of sensor and well wall must be closely, when measured in the tunnel should be no other vibration source. Instrument source near constraints, flanked by two groups, each group along the vertical direction (elevation) three focal points, each focal point is about 1m, interval of 2m (range direction), the two groups using measuring equipment (theodolite and total station) measurement sensor relative to the tunnel axis distribution and shot point precise location. TRT With more than 10kg of heavy hammer excitation seismic wave, receive wireless sensor with seismic signal, TRT source and sensor in the tunnel arrangement is shown in Fig. (**2**).

4. PROJECT PROFILE

TRT6000 system engineering application takes Jianfengling mountain tunnel of Darui line railway, of advance geological forecast for example. The tunnel line mileage D2K31+712 ~ D2K33+582, the total length of 1870m; Tunnel site belongs to tectonic denudation middle-mountain landscape, the terrain ups and downs is bigger, the natural slope of 15°-40°local steep; The ground elevation 1545-1694 m, 129 m from the relative elevation difference, Mouth of the slope zone near the surface of vegetation and quaternary residual soil, slope wash loose debris cover, scattered exposed bedrock. On the underlying bedrock mainly for the Jurassic series group mudstone folder sandstone bars on the road, joint fissure development, crushing of rock mass, rock weathering and strongly weathering zone thickness is bigger. Period of groundwater is mainly for bedrock fissure water, walk near the tunnel line's surface there are perennial water in the valleys, flow rate is about 1 L/s, no corrosive, surface water and groundwater for poor geological fault fracture zone and the tunnel line intersect. Tunnel to D2K31+821, advanced prediction set of constraints on the surrounding rock geological phenomena, such as geological sketch, detailed observations and the results are as follows: thin bedded rock for Jurassic sandstone, tendency N352° W, 13°-18°inclination, crack development, rock joints are local fracture cleavage dense (1-2cm), the broken rock mass block, weathering degree is weak to moderate, continuous water, groundwater status to Ⅲ, local fault gouge, surrounding rock classification to Ⅴ constraints of geological sketch as shown in Fig. (**3**).

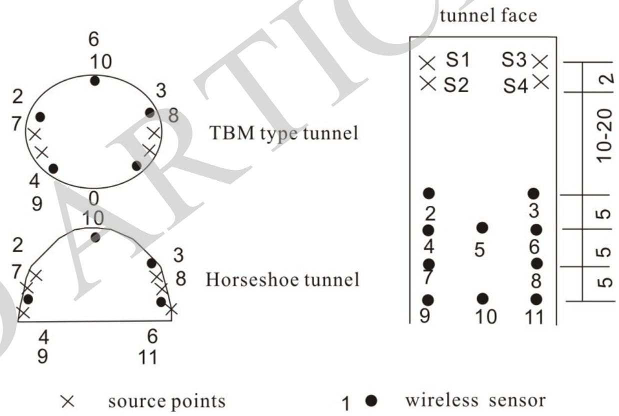

Fig. (2). Layout of TRT6000 seismic source and sensors (Unit: M).

5. RESULT

Heavy hammer source seismic wave in TRT system adopted wireless sensor module seismic signal receiver, inside the sensor to convert the modulus of the coma to the total collection base station directly, again by the base station transmission to the laptop, to realize the collection of signal receiving work. Acquisition of TRT data, processing, sorting and filtering by TRT software and assume that a wave speed model, according to the seismic signal of sensor or detector receives the get a wave propagation time, using the wave velocity after initial model for computing theories of adverse geological distance, get geological tomographic scanning imaging figure (as shown in Figs. **4**-**6**), The forecast range in the direction of tunnel length is 160 m, width is about the center line of the tunnel and 20 m, height is 40 m, the position of constraints is 31.1 m in the figure, the image shows the front clear tunnel surrounding rock geological structure.

Fig. (**4**-**6**) dark areas represent negative reflection coefficient is bigger, show that the area may be lower seismic wave propagation velocity and the common local seismic waves break, loose or the poor geological area for water makes the seismic wave amplitude attenuation obviously and wave velocity decrease! Seismic shear waves can't through the water area, can form strong reflection, can be seen from

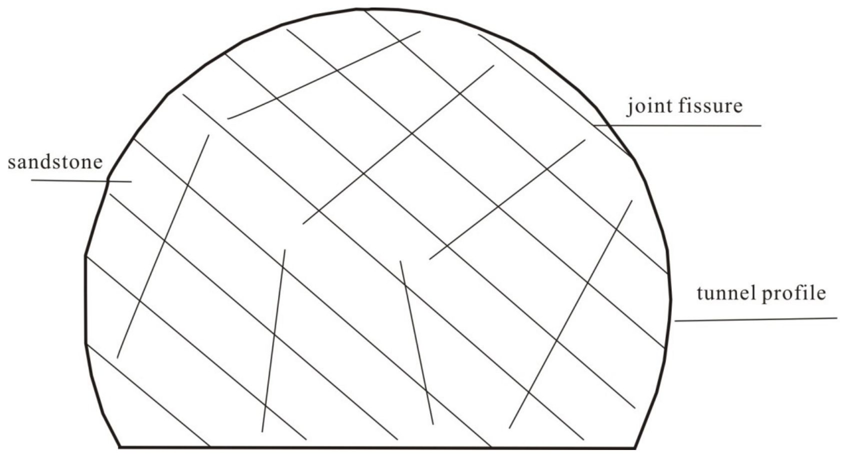

Fig. (3). Geological Sketch Of Tunnel Face On D2k31+821.

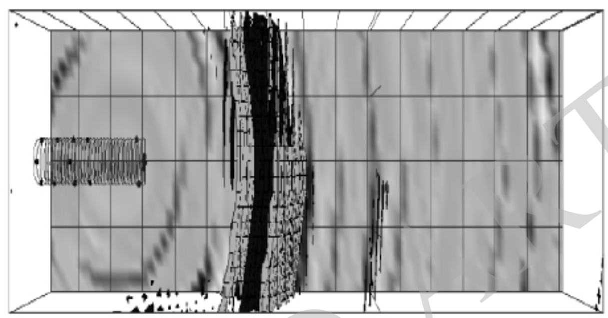

Fig. (4). Advanced Geological Prediction Of TRT6000 (Overlook).

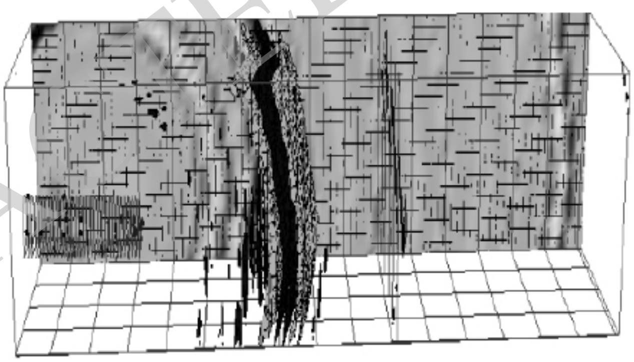

Fig. (5). Advanced Geological Prediction Of TRT6000 (Lateral).

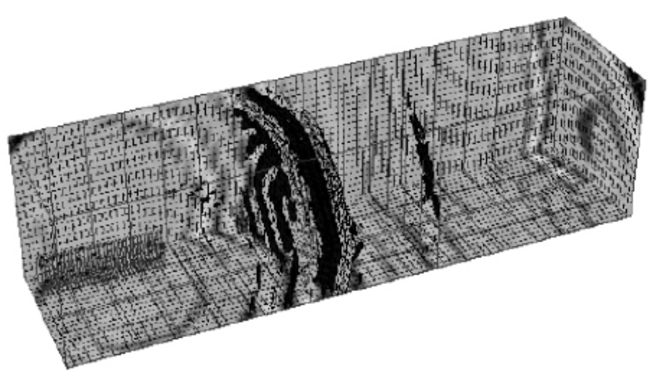

Fig. (6). Advanced Geological Prediction Of TRT6000 (3D)

Table 1. Geology condition of tunnel excavation.

NO	mileage	Length(m)	Geological excavation situation
1	D2K31+821~D2K31+855	34	Surrounding rock is broken with mud, Jurassic sandstone
2	D2K31+821~D2K31+881	26	Fault fracture zone, joint fissure development
3	D2K31+821~D2K31+951	70	No obvious adverse geological structure, joint development, pore water

the diagram, the stability of surrounding rock in general is good, but in the presence of local soft rock strata and the development of fissures is the location, the stability of surrounding rock will be worse. D2K31+821-856(35m) period forⅤlevel of surrounding rock, this thin bedded surrounding rock Jurassic sandstone, the broken rock mass, joint fissure development, containing a small amount of fracture pore water; D2K31+856-881(25m), period of surrounding rock strength, joint crack development, for the fault fracture zone, which basic classification of surrounding rock toⅤ groundwater status to Ⅲ level; D2K31+881-951 (70m) forⅤlevel of surrounding rock, the segment detection did not find large adverse geological structure of surrounding rock, joint fissure development, pore water penetration. Through geological advanced prediction of Jianfengling mountain tunnel of Darui line railway, combined with the survey and design data, and constraints to the excavation of tunnel surrounding rock conditions, geological conditions are shown in Table **1**, the excavation surrounding rock excavation results are basically consistent with TRT detection.

According to experience, convergence curve in the early stages of tunnel clearance is not suitable for using the exponential function of convergent to regression analysis. Therefore, this paper does regression analysis based on the data of 22 days later. Using the principle of least square method, the net convergence data regression analysis, and obtain the regression curve, the regression curve is $u = 3.893e^{-1.2631/t}$. The curve shows that the section is clear convergence maximum cumulative $y_w = 3.893$mm, and predicts that the surrounding rock and supporting structure deformation are stable. In fact, the follow-up monitoring data basically has the trend of regression curve prediction.

CONCLUSION

TRT advance geological forecast system prediction distance, simple operation, high degree of automation of machine, no effect on construction, the observation way to achieve the three dimensional space observation, data processing method, seismic tomography has been adopted and forecasts range from 90-200m. TRT constraints can accurately identify the distribution of geologic body in front, the fault fracture zone, joint development situation, water and other bad geological phenomenon has higher resolution. In construction process, according to the actual situation of project, rational arrangement of measuring line and combining the detection result, constraints of tunnel excavation and the tunnel area geology comprehensive demonstration, the result of the test for effective advance geological forecast, prevent the tunnel water inrush, sudden mud, gas etc. May form of severe accident, improves the progress of tunnel excavation, geological disaster risk will reduce to a minimum. Application of TRT system is unable or difficult to detect these aspects of TSP system, such as size and characteristics of karst fillings, etc., which has yet to be further research and development. Using regression analysis model, based on the regression analysis of the effective engineering, the monitoring data of late verified the accuracy of the regression analysis results in this paper.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

Declared none.

REFERENCES

[1] Li, Y. H., Xu, G. L., Yang, Y. H., Wang, J., & Dong, J. Y. “Application of earth-quake refracted wave method to geological prediction for tunneling.”.*Chinese Journal of geotechnical engineering*, 200, vol. 27, no. 10, pp. 1180-1184.

[2] Li Shucai, Li Shuchen, Zhang Qingsong, *et al.* “Forecast of karst-fractured groundwater and defective geological condition”. *Chinese journal of rock mechanics and engineering,* 2007, vol. 26, no. 10, pp. 217-225.

[3] Xu Zemin, Huang Ruiqiu. “Deep-lying supper-long tunnel and construction geology disaster. ”*Southwest Jiaotong University press*, 2000.

[4] He Daliang, Li Cangsong. “The development of geological forecast in tunnel construction. ”*Chinese Journal of modern tunneling technology*, 2001, no. 3, pp. 12-15.

[5] Song Xianhai, Gu Hanming, *et al.* “overview of tunnel gological advanced prediction in china. ” *chinese journal of progress in geophysics*, 2006, vol. 21, no. 2, pp. 605-613.

[6] Li Chunlin, Li Tianbin, *et al.* “Primary support stream tunnel monitoring measurement and a preliminary study on the gy. ”*Journal of geological hazards and environmental protection*, 2007, vol. 17, no. 4, pp. 85-90.

[7] Shi-bao, SHI Chun-hui1 ZHANG, and H. A. N. Ai-min. "Dynamic Monitoring and FEM Simulation Analysis in Highway Tunnel Construction." *Jiangsu Construction* 1 (2010): 008.

[8] Chen Jianhua. “ Advance geological prediction and monitoring in construction of the tunnel. ” *Construction of Shanxi Province*, 2009, Vol. 35, no.10, pp. 335-336.

[9] Meng Lubo. “Highway tunnel informatization construction and computer aided decision-making system research. ” *Chengdu: Chengdu University of technology master's degree thesis*, 2004.

[10] Shi Guangde, Hu Dejun, Xing Kexuan, *et al.* “The setting of the deep foundation uni-axial shores and node technology cessing. ”*Journal of construction technology*, 2002, vol. 31, no.1, pp. 28-30.

[11] Jun, S. U. N., and Zhu Hehua. "Mechanical Simulation and Analysis of Behaviour of Soft and Weak Rocks in the Construction of a Tunnel Opening." *Rock and Soil Mechanics* 15.4 (1994): 20-33.

[12] shen Yusheng, Zhao Yuguang. "Double-linked-arch tunnel surrounding rock stability of the fuzzy probability analysis research. " *Journal of geotechnical engineering*, 2005, no. 11, pp. 1358-1361.

[13] Wang Guoliang. "Highway tunnel construction monitoring. "*Journal of Shanxi architecture,* 2009 (31): 320-321.

[14] Hu Yuyuan, "He Hui. Headroom tunnel convergence measurement and data analysis research. "*Journal of information science and technology*, 2011, no. 7, pp. 259-260.

Received: May 26, 2015 Revised: July 14, 2015 Accepted: August 10, 2015