Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 189 (2017) 737 – 743

Procedia Engineering

www.elsevier.com/locate/procedia

Transportation Geotechnics and Geoecology, TGG 2017, 17-19 May 2017, Saint Petersburg, Russia

Monitoring of quarry slope deformations with the use of satellite positioning technology and unmanned aerial vehicles

D.V.Beregovoi, J.A.Younes, M.G.Mustafin *

Saint-Petersburg Mining University, 21-st line V.O., 2, 199106, Saint Petersburg, Russia

Abstract

In the article we describe the method of arrangement of monitoring of pit slopes deformations, which differs significantly from the traditional (statutory) approaches. We use modern methods of observation: satellite positioning technology and air drones. The original technology of satellite measurements is used to provide control stations, to which subsequently survey points using air drones are connected. Point cloud is optimized leaving the required amount. Irregular filtering is applied, which is the basis for the pit models. Potential danger zones of pit slope, which are compared during observations cycles, are allocated on the basis of modeling of the deformed rock condition. This method allows using digital models of centimeter accuracy.

Peer-review under responsibility of the scientific committee of the International conference on Transportation Geotechnics and Geoecology

Keywords: deformation monitoring, displacements, coordinates, satellite positioning technology, air drones, a digital model ;

Main text

Ensuring efficient and safe conditions for mining works at the open-pit method of development of mineral deposits is much dependent on the establishment and control of open-pit stability. Existing regulations specify that the deformation process control is focused at observation of the Earth's surface. At the same time the official observation techniques use tools corresponding to the issuance of the first instructions for observations, i.e., a few

* Corresponding author. Tel.: +7-812-328-8684; fax: +7-812-328-8684.
E-mail address: mustafin@spmi.ru

Peer-review under responsibility of the scientific committee of the International conference on Transportation Geotechnics and Geoecology
doi:10.1016/j.proeng.2017.05.116

decades ago [1]. Therefore, an urgent task is to solve two problems: to study of the mechanism of industrial landslide and the ability to control the deformation process of the near-edge zone by so-called non-contact, remote methods.

If we speak of observations over deformations on mining sites, of course, it refers to the model-driven approach. First we design an object model, simulation of the deformation process and then the observing system. Modeling of pit wall deformations is made with the help of "NEDRA" software system [2].

The pit model is shown on Fig. 1, a. To identify the nature of the pit slope deformation we take a flat model. Model dimensions: width – 320 m, height – 160 m. The pit is modeled by the goaf of 256 m on the upper edge and 160 m on the upper edge. Slope angle is 52 degrees. Due to symmetry, we analyze half of the model (see. Fig. 1, b). Rocks accommodate soil in a pit of 16 m, elasticity modulus (E2) is 20 MPa, compressive resistance (σ2) is 10 kPa, adhesion is C2 is 3 kPa, the internal friction angle (φ2) is 30º, the proportion of species (γ2) is 14 kN/m3, below there is solid clay interbedded with mudstone with a capacity of 96 m, E3 is 200 MPa, σ3 is 0,5 MPa, C3 is 67 MPa, φ3 is 30º, γ3 is14 kN/m3. We solved the problem with elastic plastic by Coulomb-Mohr failure criterion [2, 16, 17, 18]. Limiting conditions: the upper limit is free, on the left and the right the horizontal movements are prohibited, the lower limit is fixed.

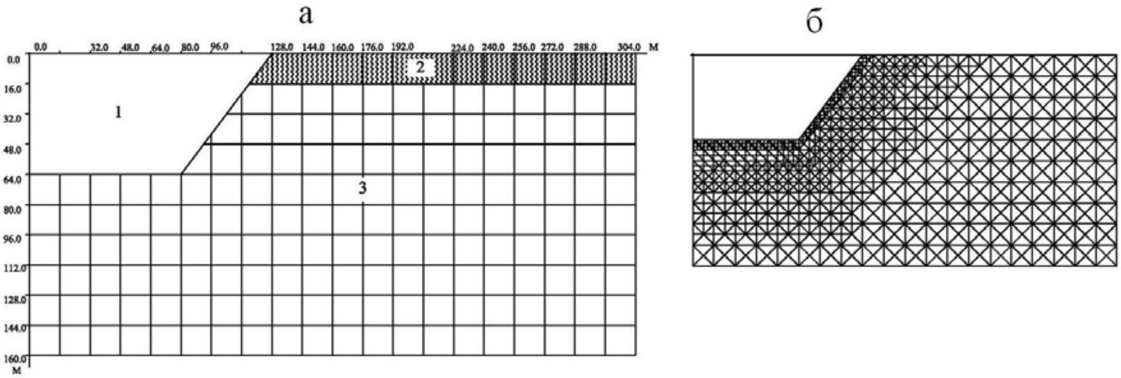

Fig. 1. (a) Pit model: structural; (b) finite element.

Registration of observations on the Earth's surface, which are settled in the regulations, apparently are accepted according to the result of solving the problem of plastic elastic deformation of the body, the formation of a cavity in it with vertical or inclined outcropping. This body mostly experiences displacement at the upper limit (the Earth's surface), which is confirmed by the respective graphics [1].

During modeling the stress-strain state (SSS) of rocks in the model shown on Fig. 1, we got the following picture of the deformation process (fig.2-3).

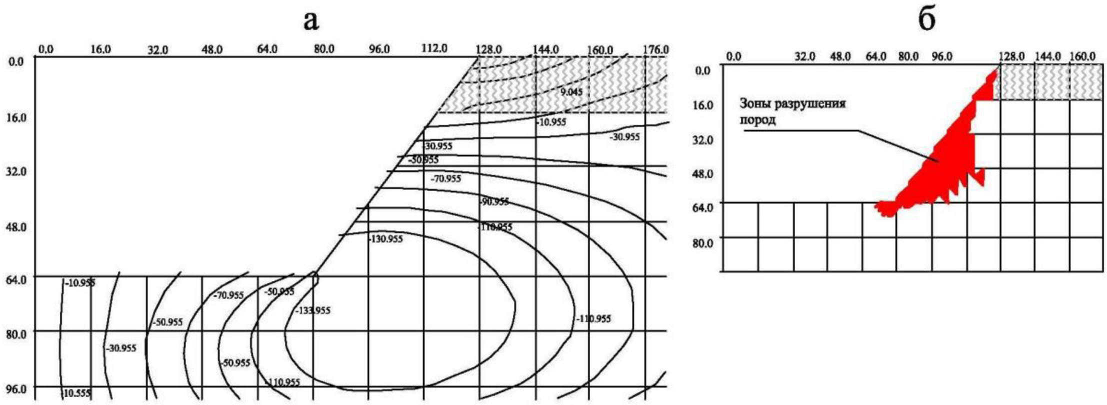

Fig.2. (a) Distribution of horizontal displacement, (b) the picture of the destruction zones in the first stages of the process of elastic plastic deformation of rocks

As it can be seen from a Fig. 2, the deformation and destruction process begins on the bottom edge of the pit slope. Displacement on the elastic stage is already 13 cm. On the upper edge due to elastic recovery (vertical displacements up) horizontal displacements are of opposite sign.

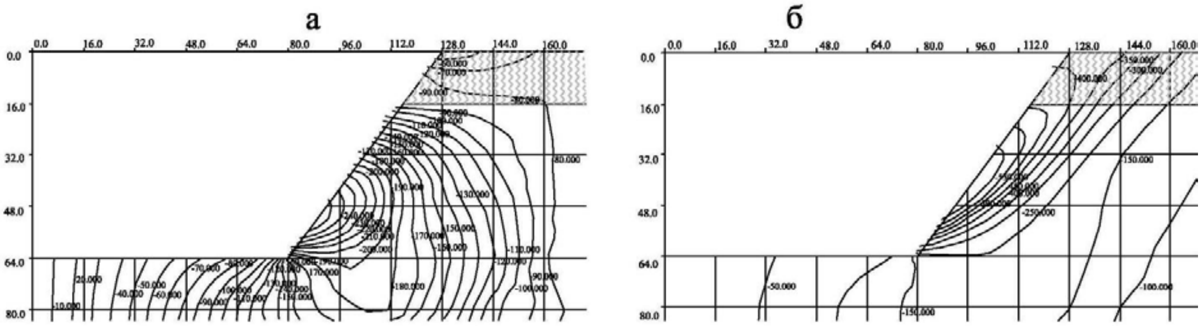

Fig.3. (a) Distribution of horizontal displacements at the intermediate, (b) the final stages of the formation of a slope landslide

Further development of the deformation process of an open-pit slope is accompanied by a bigger destruction and deformation of the bottom of the rock slope. Deformations can be up of 25 cm or more (see Fig. 3a), i.e. twice the size of the plastic elastic deformation. At the upper border (the Earth's surface) near the edge direction of deformation is directed at the pit, and it is caused by failure of the masses. The final stage of destruction in the slope (before the final failure of the masses) shows the distribution of the deformation process, which started on the lower edge of the pit, towards the earth's surface.

Thus, we can conclude that the observation over the deformation process at the open pits should be focused at the measurement of displacements on the lower edges of the pit. Observations over the deformations of the earth's surface allow us to capture the final stage of the failure process. We should point out that, of course, it is not easy to arrange observations with the same accuracy as on the earth's surface.

However, you may notice that the landslide process has its stages of rock deformation. As it was shown, first the links must be broken and transferred to the ultimate state of rocks at the bottom edge of the open pit. This causes deformation (uplift) of the rocks. After that, the overlying part of the slope partly loses its support and it freezes. Within future slip plane elevated shear stresses appear. Under the weight of a formed prism, the destruction process develops upwards within the slip plane. Also a dynamic balance emerges. Large masses of rocks are in quasi-mounted state and are held only by the cohesive forces in the upper and surface areas of a rock array. Balance of retention and shear load along the slip plane, the adhesion surface area to the volume overhanging rocks determines the dynamics of the landslide process. Moreover, failure and landslide can be initiated by natural factors that modify the properties, such as rock humidity.

The described mechanism of industrial landslide allows us to adjust methodology of field observations. Instructive measurements on the earth's surface are performed with millimeter accuracy. The correctness of this approach is verified by numerous observations. Nevertheless, the observations at the lower edge of the pit may be performed with centimeter accuracy. The evaluation of the pit slope stability can be carried out by the excess of the horizontal displacements in the slope bottom of the pit, above the dimensions of deformation corresponding to the rock deformation in the plastic elastic mode.

The critical (limit) elevations may be adjusted within the scientific research. The approximate limits can be exceeding of 10 percent. Then, the measurements can be performed in centimeter accuracy range. This allows us to apply one of the modern efficient technologies – air drone shooting, which has the accuracy in the centimeter range.

Application technology of an air drone complex includes two stages. The first is to provide a coordinate basis which is performed by using satellite positioning [9, 11] and the second one is the actual application of an air drone complex.

Modern satellite receivers allow to provide high positioning accuracy [10], but the main task is to achieve sufficient accuracy when creating a new network for further thickening and performing different surveying tasks. To achieve this goal we developed a technology for planned geodetic networks measurement with the help of satellite triangulation and original way of direct measurements, called by Younes a "leap frog", which means streamlining the transition of a satellite receiver from one point to another (Figure 4), [3].

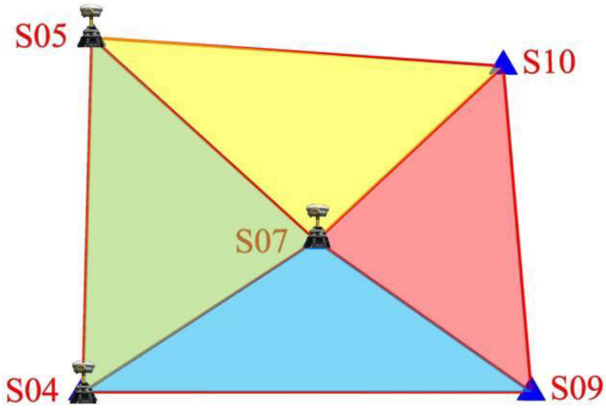

Fig.4. A diagram of satellite triangulation

The sense of this technology is that the static satellite measurements are carried out in two sessions during different times of day, the duration of the observation period depends on the base lines length (but not less than 2 hours per session). The technology involves the simultaneous positioning of the three points of the triangulation network with the subsequent transition to the adjacent triangle, while the equipment remains on the points of the adjacent side.

The research results showed that the accuracy of the points position inside the network is provided within a centimeter or less, which is a required accuracy in most projects.

Currently, a growing number of mining companies apply air drone complexes, equipped with a digital camera. Via these mobile systems with remote control aerial photos with high resolution can be shot, which can be also processed to produce high-precision aerophotoplans and 3D models [8].

Air drones application has a lot of advantages compared with traditional air shooting. One of the main ones is that we should recognize that this aircraft has quite compact size and, therefore, can boast of mobility, portability and affordability. This system is easy to be installed in a short time and requires only one person to do all the shooting. Air drones are typically used at a height below the cloud cover, which makes it less dependent on weather conditions [5]. Other advantages of this shooting method should also be noted: almost complete automation, high productivity and relatively low cost of equipment.

The whole problem included the creation of a three-dimensional model of the pit and its surrounding areas according to shooting and evaluation of the accuracy of its construction. Shooting is performed using an SLR camera attached to an air drone. We should also identify the main advantages and disadvantages of this method in the performance of the field works and off-site works too.

Field works were carried out in the “Preg” pit (Pronat Steinbruch Preg GmbH), which is located not far from the city of Leoben, Austria. It is a well-known open pit in Austria, where the Schwarzl gruppe company produces solid rock (Fig. 5). Its planned dimensions are 160 to 180 (m) and the height difference is around 120 m [4].

Fig.5. Pit Preg. The left image is a photo taken with the Google Maps satellite. The right image is a photograph taken in the pit.

Before our aerial shooting, we established control points whose coordinates had been predetermined by satellite. Their marks were specially created by Graz Technical University (Fig. 6) [7].

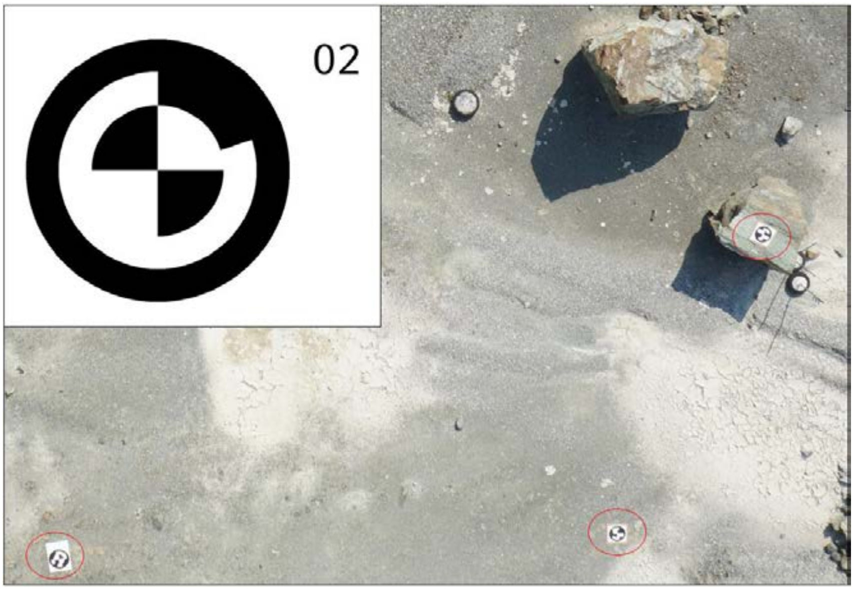

Fig. 6. An example of a control point, designed by Graz Technical University

Works were carried out using an air drone "Tarot Frame" with controller "DJI NAZA M V2", created specifically for the Leoben Mining University [6], and by the camera "Sony Alpha 6000" (24 MP), which was calibrated in the beginning. After the the preparatory work the air drone was launched and it started shooting. Photos were made every 3 seconds. Totally there were 4 flights, 7 minutes each, and as a result the open pit was shot from different heights and at different tilts of the camera towards the horizon. The shooting time, including the preparatory work, was lasting for 2 hours and then the photos were exported to a computer for further processing.

Data processing was performed with the help of a software product (SP) PhotoScan developed by the Russian company Agisoft. The algorithm is shown on Fig. 7 [12].

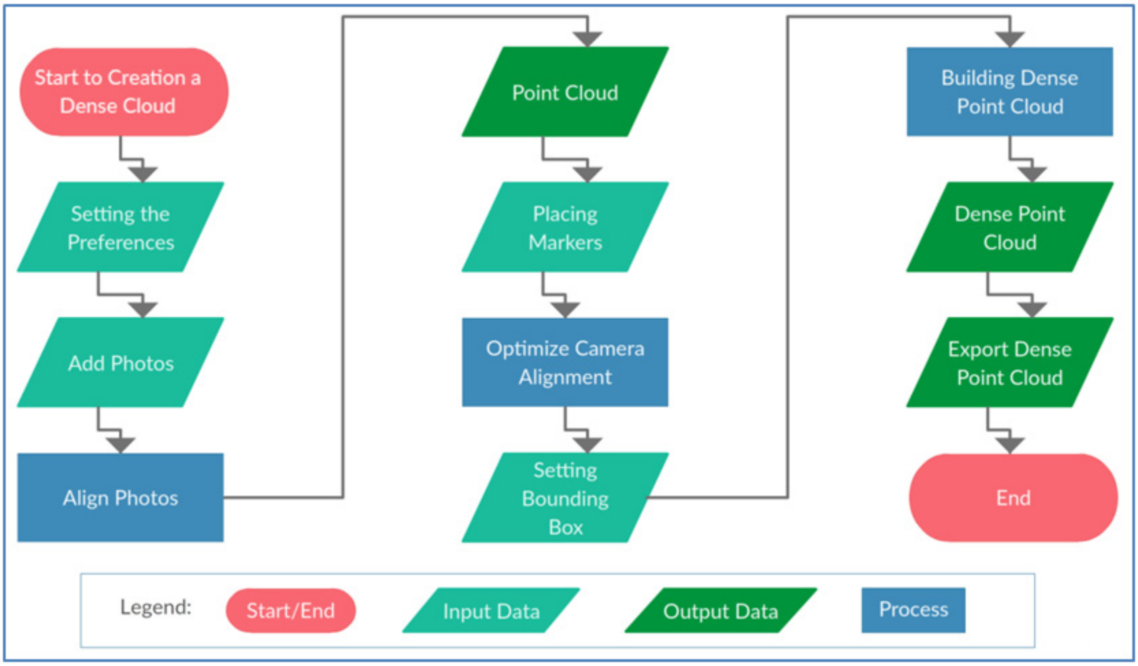

Fig. 7. A block diagram for designing a dense point cloud in PhotoScan program

A significant obstacle to application of this method is processing of a large array of a point cloud, which requires a significant period of time when using the computer processor of an average level. In these studies we used a computer with 4 GB of RAM. Processing 306 images of medium quality took us about 24 hours. Therefore, there is need to improve the algorithm for developing a "lightweight" point cloud, for example, with the help of point filtration [13]. Of course, you can continue using powerful computers, but sooner or later one will have to solve the problem of developing "a lightweight" point cloud.

After image processing we got a dense cloud of 27.8 million pixels. Comparison of the coordinates of control points obtained by surveying and air drone shooting indicated that RCS was 8.3 cm [15].

The final step was the creation of a three-dimensional model of the pit surface according to the previously made dense cloud of points by constructing a Delaunay triangulation (Fig. 8) [14].

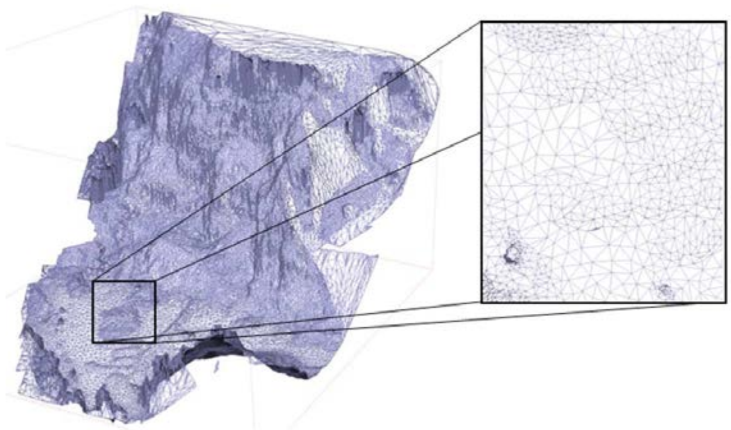

Fig. 8. Delaunay triangulation model, a pit to the left, mounds to the right.

Thus, we built a three-dimensional model of a pit, consisting of 27.8 million pixels. Their average square error with respect to the control points is 8.3 cm, which corresponds to the scale 1: 1 000 and allows to plan and design work in the pits.

Conclusion

We explained the reason of geomechanical monitoring arrangement in the pits using modern geodetic technologies. The principal issue in the article is a model-driven approach to observations. We described the slope deformation mechanism of the open pits. We suggested considering the entire construction of the pit wall: the lower edge and the earth's surface near the upper edge. The preliminary size of ultimate deformations was specified. We showed that it is possible to control the deformation process within the centimeter range. The prerequisites for carrying out observations using drones were created.

Shooting of the open mine workings with the help of drones is expected to be effective in the nearest future, due to the lower price of equipment and development of software that will be widespread among other shooting methods.

At the moment we can highlight the following errors in the used software: the possibility to process only their own brands and the long time of processing. The advantages of the proposed method are the following: high performance and low cost of field works, a large quantity of functions, camera calibration and maintenance treatment of oblique photos. The demonstrated technique can be used to control the deformation process of pit slopes.

References

[1] Instructions on observations over deformations boards, slope faces and dumping sides in the pits and development of measures to ensure their sustainability, Leningrad, RRIMGS, 1971, p. 104.
[2] M.G. Mustafin, I.M. Petukhov, The main factors leading to the emergence of rock bumps with the sole destruction, Mining informational and analytical bulletin, Moscow, Moscow State Mining University, 2002, № 11, pp. 17-22.
[3] J.A. Younes, The question of increasing the accuracy of geodetic networks by satellite observations, Collection of scientific works, St. Petersburg Mining University, SPB, 2016, pp. 73-74.
[4] Pronat Steinbruch Preg GmbH, Schwarzl-Gruppe Company, http://www.schwarzl-gruppe.at/index.php?id=2966. – 03.11.2016.
[5] Unmanned Aerial Vehicle (UAV) mapping, Geoinformation Company Blom, http://www.blomasa.com/main-menu/products-services/aerial-survey.html. – 03.11.2016.
[6] Mining University, Leoben, https://www.unileoben.ac.at/. – 03.11.2016.
[7] Technical University, Graz. https://www.tugraz.at/home/. –03.11.2016.
[8] Robert Lautenschlager, UAVs in the Mining Industry, GIM International, UAS Special, 2015, Issue 1, pp. 29-31.
[9] J. P. Malet, O. Maquaire, E. Calais, The use of Global Positioning System techniques for the continuous monitoring of landslides: application to the Super-Sauze earth flow (Alpes-de-Haute-Provence, France), Geomorphology, Elsevier, Netherlands, 2002, pp. 33-54.
[10] A.E. Ragheb, S.J. Edwards, P.J. Clarke, Using filtered and semi-continuous high rate GPS for monitoring deformations, American Society of Civil Engineers, Journal of surveying engineering, Том: 136, №: 2, США, 2010, pp. 72-79.
[11] Eric Ma, Yongqi Chen, Xiaoli Ding, Monitoring of slope stability by using global positioning system (GPS), Hong Kong Polytechnic University, Hong Kong, pp. 298-310.
[12] Http://www.agisoft.com/pdf/PS_1.2 -Tutorial (BL) - Orthophoto, DEM (with GCPs).pdf
[13] Http://www.cloudcompare.org/doc/wiki/index.php?title=Edit%5CSubsample
[14] T. Luhmann, S. Robson, S. Kyle, I. Harley, Close range photogrammetry: Principles, Techniques and applications, Whittles Publishing, Dunbeath, 2011, p. 91.
[15] C.D. Ghilani, P.R. Wolf, Elementary surveying: an introduction to geomatics, 13th ed., Prentice hall, 2012, pp. 55-57.
[16] O.C. Zienkiewicz, R.L. Taylor, D.D. Fox, The finite element method for solid and structural mechanics, 7th Edition, Elsevier, 201, p. 657.
[17] D. Stead, J.S. Coggan, D. Elmo, M. Yan, Modelling Brittle Fracture in Rock Slopes Experience Gained and Lessons Learned, Slope Stability 2007, Proceedings of the 2007 International Symposium on Rock Slope Stability in Open Pit Mining and Civil.
[18] L.W. Abramson, T.S. Lee, S. Sharma, G.M. Boyce, 2002, Slope stability and stabilization methods, John Wiley&Sons, Inc. New York, USA.