Contributions of Surveying in the Development of Regional Infrastructures – An African Perspective

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Key words: surveying, spatial data, reference frame, infrastructural development

SUMMARY

Since its modest beginning in ancient Egypt where it was used to re-establish the boundaries of farm holdings after their obliteration by the annual floods, surveying has widened in both scope and spatial coverage. With time, it became an indispensable tool in all extensive projects involving spatial data. In order to be useful, the spatial data must all be tied to the same reference frame or to different reference frames whose relationships can be determined. This requirement severely restricted infrastructural developments to areas within one geodetic reference system, usually a nation. As cooperation between countries within regions increased, it became necessary to extend infrastructural developments across national frontiers. Following this new attitude, a number of laudable regional projects have been conceived. One such project is the channelling of some waters of Oubangui River at Palambo in Central Africa Republic, through a navigable canal, to Lake Chad in north-eastern Nigeria. This paper examines the contributions of surveying in the development of such regional infrastructures. It also discusses the challenges posed by the existence of heterogeneous geodetic datums in the development of regional infrastructures and supports the establishment of a unified reference frame for Africa.

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1. INTRODUCTION

1.1 Definitions

Surveying has been described as a mathematical science used to determine and delineate the form, extent, and position of features on or beneath the surface of the earth (Encarta, 2005). It includes the determination of positions by the use of Global Navigation Satellite Systems (GNSS). Since its modest beginning in ancient Egypt where it was used to re-establish the boundaries of farm holdings after their obliteration by the annual floods, surveying has widened in both scope and spatial coverage. With time it became an indispensable tool in all extensive projects in which spatial data are involved. The increase in spatial extent necessitated that geodetic principles be employed so that the curved nature of the earth's surface is taken into account. This is the case with surveys undertaken for the establishment of regional infrastructures.

A *region* is a collection of places with similar characteristics and which is distinguished from other regions by these unique attributes (Encarta, 2005). Thesaurus dictionary describes a region as a large, usually continuous segment of a surface or space; an area.

Infrastructure is a compound word with a Latin component *infra* which means below. Infrastructure, therefore, literally means below structure, or the foundation on which a structure is built. This can be widely embracing. The Ministry of Economic Development of New Zealand (MED, 2005) recognizes that there is no universally accepted definition of infrastructure but agrees there is broad agreement about what it is and is not. Quoting Macmillan dictionary of modern Economy (1996) it defines infrastructure as 'the structural elements of an economy that facilitate the flow of goods and services between buyers and sellers." Elaborating and quoting the Rutledge Dictionary of Economics (1995) it broadens the definition to include "the basic services or social capital of a country, or part of it, which make economic and social activities possible by providing transportation (and other facilities) in which community activities can take place. From these definitions, such assets as roads, railways, airports, sea and river ports, canals, telecommunications and other basic physical systems of a country's population that make economic and social activities possible can be identified as infrastructure.

1.2 Genesis of a Typical Infrastructure

Few regional infrastructures are conceived and implemented as such from the onset. These infrastructures usually start at a local level, compelled by the needs of the local community.

With time, however, a number of local infrastructures merge to become a national infrastructure, or part of it.

The stages in the development of an infrastructure can be illustrated with a hypothetical road development between three primitive communities, A, B and C with B lying roughly between A and C. A communication route naturally starts between A and B. Another communication route similarly starts between B and C. With time these routes are adopted and maintained by the local government authority. Several communities may ultimately be linked in this way. The local government roads may in turn be adopted by the national government of the country and integrated into the national road network. Occasionally, an entirely new road is planned and constructed to link communities.

2. REGIONAL INFRASTRUCTURES AND SURVEYING

2.1 Transportation

Transportation constitutes one basic infrastructure. The commonest means of public transport are by road, rail, air and water.

2.1.1 Roads

These days, the construction of the hypothetical roads discussed above would be preceded by the acquisition of an image of the area in question. Thereafter, a digital terrain model of the selected corridor would be prepared. Such a model, which should provide information on cross sections and longitudinal profiles, among others, will provide information for determining earthwork quantities and for taking a sound decision on the road project. Surveying will also come in during the setting out of the project.

Following increased cross-border cooperation and activities, it became desirable to integrate the road network across national borders and within the entire African region. The International Road Federation has identified nine Trans African Highways (TAH) namely (ADB/UNECA, 2003):

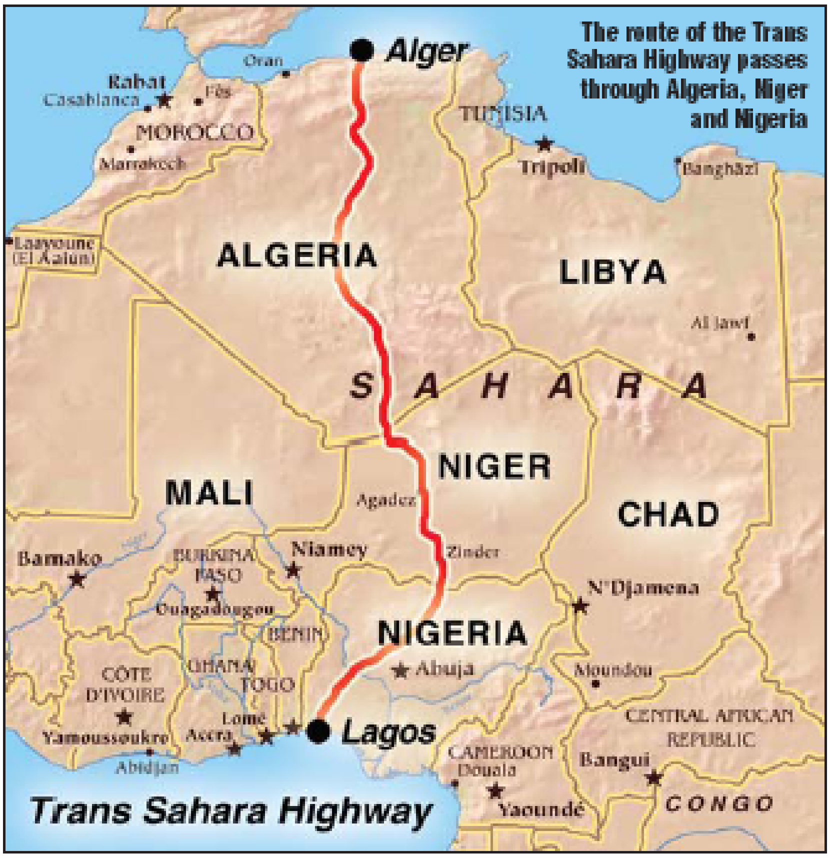

Figure 1: The Lagos-Algiers Trans Sahara Highway:
Part of Trans African Highway Network
Source: IRF, 2004.

TAH 1: Cairo to Dakar 8,640 km
TAH 2: Algiers to Lagos 4,500 km
TAH 3: Tripoli to Windhoek 9,610 km
TAH 4: Cairo to Gabarone 8,860 km
TAH 5: Dakar to N'Djamena 4,500 km
TAH 6: N'Djamena to Djibouti 4, 220 km
TAH 7: Dakar to Lagos 4,010 km
TAH 8: Lagos to Mombasa 6,260 km
TAH 9: Beira to Lobito 6,520 km.

The Lagos to Algiers Trans Sahara Highway, which is part of the Trans Africa Highway network, is shown in figure 1. These transcontinental roads often contain gaps (missing links). According to an ADB/UNECA consultant's report (IRF, 2004): "Cross border missing links are generally due to the TAH alignment passing through a border area between two countries with little trade and where the area itself is of little interest to one or both countries."

2.1.2 Railways

Surveying has contributed to the development of African transportation infrastructure in other ways. Railways serve as an important means of conveying goods within the hinterland. According to *Railways Africa* (2006), the 30.2 million km^2 continent of Africa has a total track length of 89,390 km. This is unevenly distributed as follows:

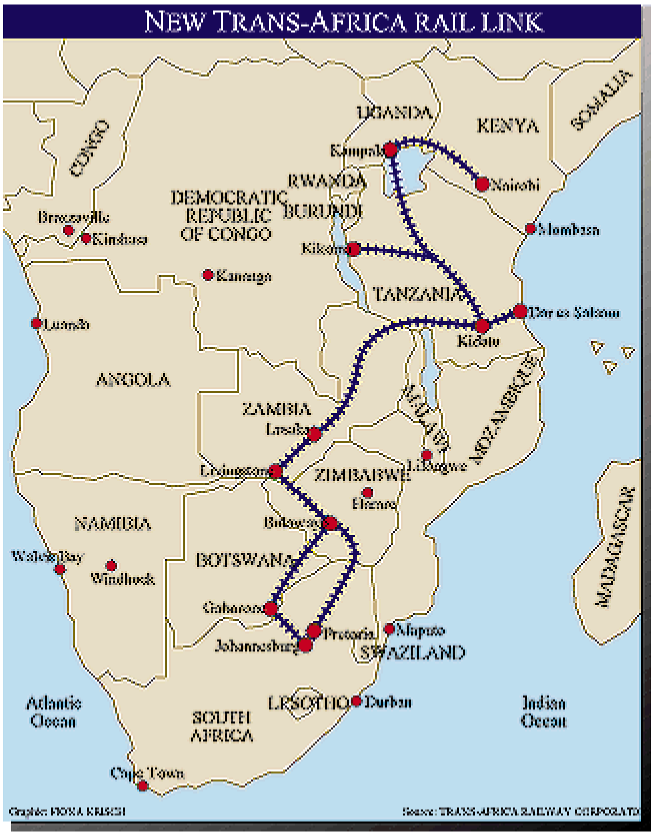

Figure 2: The Southern Africa Rail Link
Source: Don Robertson

Southern Africa:	38,513 km
North Africa:	19,931 km
East Africa:	19,293 km
West Africa:	9,717 km
Central Africa:	2,526 km

The Southern Africa rail link is shown in figure 2. As can be seen from the figure, transportation by rail is well developed amongst the Southern Africa Development Community (SADC) countries. This has been encouraged by a combination of free trade and the existence of a common geodetic reference system for the sub-region. According to the *Africover* project report, Tanzania's horizontal network is based on the arc of 30th Meridian. The coordinates were based on the datum in Zimbabwe which in turn was derived from another datum in Southern Africa. The datum was also used to establish control points in the

Democratic Republic of Congo and Mozambique. The situation thus provided a uniform system from the Cape to the Equator. As we have seen, West and Central Africa do not have their fair share of the continental railway network. Development of a sub-regional railway network within the West African sub-region has been hampered by interlocking boundaries of countries with different geodetic reference datums and without much trade. Although the Blue Nile Datum, often erroneously referred to as Adindan Datum (Mugnier 2005), is the reference datum used by the largest number of countries in West Africa, several other reference datums exist. The following list, extracted from NIMA (1987), gives the various datums in use within the sub-region.

Adindan (Blue Nile): Burkina Faso, Mali, Senegal
Dabola : Guinea
Leigon: Ghana
Liberia 1964: Liberia
Minna: Nigeria
Point 58: Burkina Faso, Niger
Bissau: Guinea Bissau
Sierra Leone 1960: Sierra Leone

2.1.3 Air Transport

Air transport is becoming significant in the continent of Africa. Growth in air transport has been encouraged, in part, by improvements in air safety. Surveying has contributed to improved runways and in the installation of navigation aids at the air ports. According to *Africa and the Middle East* (2005), the International Air Transport Association (IATA) and the FAA have partnered in a project to develop Global Navigation Satellite System (GNSS) procedures for 26 air ports in 14 states in the Southern Africa Development Community. The project, scheduled to be completed in 2002, involved conducting geodetic (GPS 84) surveys at each of the airports. It also included the development of the 104 GNSS procedures for all the airports. These GNSS procedures will enable aircraft to approach and land at the SADC airports using satellite technology.

2.1.4 Water Transport

Inland water transport is important in Africa. According to ThinkQuest (1998), the Democratic Republic of Congo alone has over 8,700 miles (13,920 km) of waterway, and barges are able to navigate at least 650 miles (1,040 km) of the Congo river throughout the year. The Congo is however not navigable in its lower reaches where there are numerous waterfalls. To facilitate transportation, railway systems have been built to connect the routes. Similarly, continuous navigation between the different sections of the approximately 4,200 km long river Niger during the flooding season is prevented by rapids (Osse, 2003). Bathymetric surveys have been fundamental to port development and the charting of navigation channels. Modern approach to bathymetry presents position and depth data in digital format which can be interfaced and related to time before data output. The two main sensors involved are the Global Positioning System (GPS) for X and Y position determination and the digital echo sounder for depth measurement. Inland Waterways Authority of Nigeria has already changed from the traditional method to this new method (Achinivu et al, 2003).

Outside the Suez Canal, transportation by canals within Africa had not been well developed. For a long time the 14 km long canal in the Copperbelt province of Zambia remained the longest canal within Africa (Moyo, 2006). Even then, the canal was used mainly for irrigation purposes. Although the canal proposed to link the Congo river at Palambo in Central Africa Republic to Lake Chad in north eastern Nigeria is also intended to replenish Lake Chad for purposes of irrigation, it will also be navigable and will boost inland water transport within the sub-region. The construction of a canal of such magnitude requires, among other things, the adoption of a common vertical reference frame so that the vertical components of the positions of widely separated points can be successfully related.

2.2 Energy Infrastructure

The development of energy infrastructure has also benefited from surveying especially in the areas of power generation and power distribution.

2.2.1 Hydroelectric Power

Hydroelectric power, as a renewable resource, is becoming the dominant source of power supply on the African continent. This is in spite of the adverse effects of the associated dams such as acceleration of flow regime, proliferation of aquatic weeds, reservoir sedimentation, and conflicting demands for water use. In West Africa alone the following hydroelectric dams have been proposed:

MAU in Ghana; Fomi in Guinea; Salthino in Guinea Bisau; Bumbuna in Siera Leone and Adjarala in Togo and Benin. Manantali in Mali and Garafiri in Guinea are already being developed. In all of the above, surveying is used to determine a suitable site for the dam. After construction surveying is again used to monitor the behaviour of the dam. The construction and monitoring of a 185m high Arch Dam in Southern Africa serves to illustrate the survey processes involved. After site selection which was based on a survey, the following steps were taken. According to Pretorius et al (2001), geodetic beacons were established in 1991 before construction started in 1995 to establish their long term stability. It was after the long term stability of the site had been ascertained that construction work commenced. After construction and putting into use of the dam, the controls were used to monitor the behaviour of the dam at specific levels of load.

2.2.2 Natural Gas

Another important source of energy which had been neglected in the past is natural gas. Natural gas deposits are not evenly distributed across the continent and while some countries have a surplus, others do not have enough. In the West African sub-region, for instance, plans are afoot to link producer and consumer nations by pipelines through the West African Gas pipeline project.

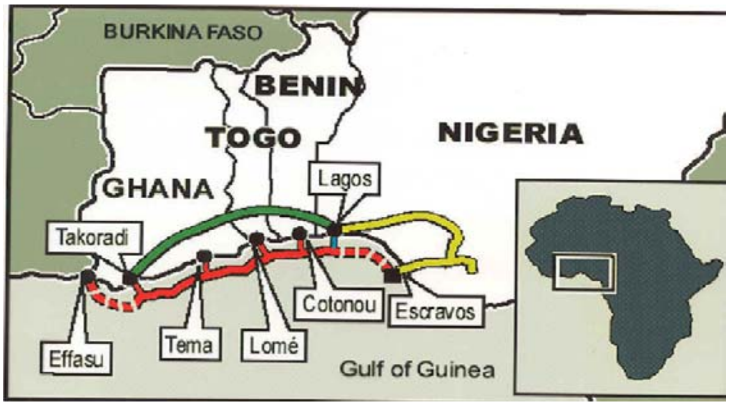

Figure 3: West African Gas Pipeline Project
Source: ECOWAS, 2006.

This project, embarked upon by Benin, Ghana, Nigeria and Togo, involves the construction of a pipeline which will make it possible for the four countries to utilize Nigeria's abundant natural gas for the generation of energy. Details include the construction of a gas pipeline between Warri in Nigeria and the border between Ghana and Cote d'Ivoire (ECOWAS, 2006). According to the Nigerian National Petroleum Corporation, NNPC (2004), the long term plan is to extend this pipeline to Dakar (Senegal) to make Nigerian gas available to the entire sub-region. Also, in Southern Africa, the Mozambique-South Africa gas pipeline project which was approved in 2002 has now been completed (ADB/NEPAD, 2006). Surveying is again used in the selection of the routes and in the other aspects of planning and execution of these projects.

2.2.3 Solar Energy

Africa holds great potentials for the development of solar energy which is considered a future source of clean and renewable energy. Due to the proximity of most of its landmass to the equator, most of Africa will have strong sunlight throughout the year. Most electrical systems in many African countries are quite obsolete as they date from the colonial era. Solar power will supplement these aging facilities. Although the use of solar power is mainly at the awareness stage in Africa, there is already a photovoltaic radio link network stretching 1,000 km along the Sinai Peninsula in Egypt (Ita, 2003). Pilot projects on solar energy have also been successfully carried out in Uganda where 100 rural home owners were given the benefit of solar electricity in their new Habitat-built homes (SELF, 2001). The many government and private field units who operate in remote and isolated areas can derive their energy requirements from solar energy. At the moment, most such units rely on the very costly-to-run electricity generating plants for their power supply. Surveying can assist in the development of this emerging infrastructure by assisting in the mapping of the location and distribution of these units.

2.2.4 Power Transmission

Strategic locations for power generation are not evenly distributed within Africa and, in the energy sector, a new attitude derived from the spirit of NEPAD (New Partnership for Africa's Development) is the pooling of energy resources. This entails the construction of long transmission lines. Surveying plays an important role in the selection of routes for these lines and in the actual setting out of the lines. The contribution of surveying in the construction of an electricity transmission line is demonstrated by the following report by Moodley (2005): "We were provided with a centre-line based on the environmental impact assessment (EIA) and were able to produce a terrain model, accurate to 15cm over a swathe 400m wide." He continues: "Based on the photography, imagery and terrain model, a precise alignment, which reduced the total cost of the power line and avoided habitation and sensitive areas, was selected". He goes on: "Having few bends in the power line and ensuring that it is as close to 180^o as possible is cost effective as it saves on steelworks. Locating power lines in areas of reasonable access away from steep slopes also helps in lowering cost."

2.3 Telecommunications Infrastructure

Surveying has also contributed to the development of telecommunications infrastructure. It provides the information required for site selection for telecommunication installations and assists in route studies where fixed telecommunication lines are involved. In mobile/cellular telephony surveying, through GIS, is capable of providing information on the caller/receiver location. Another contribution of surveying in telecommunication is rather global in coverage but needs to be mentioned. In addition to assisting in the selection of the site for the location of ground stations for a telecommunications satellite, surveying, through satellite (space) geodesy, contributes to the launching of the satellite itself. According to Richards (1986), the velocity of a satellite is related to its altitude by the equation,

$$v = r_e [\mu/(r_e + h)^3]^{0.5}$$

Where v is effective velocity of the satellite over the ground (at its sub-nadir point), ignoring earth rotation;

r_e is the earth's radius;

μ is the earth's gravitational constant ($3.986 \times 10^{14} m^3/s^2$);

h is the altitude of the satellite above the earth.

For a satellite to be geostationary, such as is usually required in telecommunications, its velocity should be equal to that of the point on the earth over which it orbits. With an equatorial radius of about 6,378,137 metres for the earth, a point on the earth's equator covers a distance (circumference) of $2\pi r$ in 24 hours giving a velocity of about 1,670 km per hour. Substituting this in the above equation, a geostationary satellite is required to orbit at a height of about 3,580 km above the earth.

3. INTEGRATION OF CROSS-BORDER INFRASTRUCTURES

We have seen that integration of cross-border infrastructures is facilitated by the existence of a common geodetic reference system. This fact has long been recognised. A notable effort at establishing a common geodetic datum for the continent of Africa was the Africa Doppler Survey (ADOS) project.

3.1 The ADOS Project

In 1981 the Africa Doppler Survey was initiated, and was completed in 1986. One of the primary intentions of the ADOS project was to establish a common geodetic datum for the continent of Africa based on the TRANSIT navigation satellite system. However, according to Ezeigbo (2001), fifteen years after the project was "completed", neither the datum, nor a unified geodetic network for the continent has been realised. The reasons why the ADOS project did not meet its primary objectives, according to Wonnacott (2005), are:

- the logistics of carrying out the observations simultaneously proved exceptionally difficult indeed;
- the rationale was not fully understood by the participating countries resulting in a lack of motivation and enthusiasm for the project;
- the project was planned almost entirely by the IAG and the international community with little input from African countries;
- there were no set observing standards and procedures resulting in observations of unacceptable standards; and
- the bilateral agreements between countries and sister organisations did not always materialise.

Nevertheless, ADOS served to provide a number of valuable lessons which will be carried forward into new efforts.

3.2 The AFREF Project

At a meeting of the Heads of Governments of African countries in 2001 a New Partnership for Africa's Development (NEPAD) was launched. This is an initiative to address the social, economic and political development of African countries, in a holistic, coherent and integrated manner, with the key objective of enhancing growth, reducing poverty and laying down the foundation for a sustainable development. It is also a framework for new partnerships to accelerate the integration of Africa into the global economy (ADB/NEPAD, 2006).

The development of regional infrastructure ranks amongst the priority areas of intervention to achieve the objectives of NEPAD (ADB/NEPAD, 2006). As already noted, cross-border integration of infrastructure which is an important step towards the development of regional infrastructure is difficult where the affected countries use different geodetic datums. This is because the planning and implementation of the integration requires the use of maps of the affected areas. The use of different datums will result in different maps which will not be helpful in the development of cross-border infrastructure. Development of regional infrastructure has thus been hampered by the existence of many geodetic datums in Africa. According to the Nairobi-based Regional Centre for Mapping of Resources for Development (RCMRD), Africa inherited very many heterogeneous datums from their colonial masters currently numbering more than 20. African governments under ECA and OAU have since recognized the need for a uniform datum and resolved that a uniform datum be established for Africa. There is now a renewed effort at the establishment of a uniform reference datum for Africa under the African Reference Frame (AFREF) project. The main objective of the AFREF project is to establish a unified datum by using the Global Positioning System (GPS) method. Although the ITRS (International Terrestrial Reference System) is the global terrestrial reference system officially adopted by the IAG (International Association of Geodesy), the WGS 84 reference system of the GPS was chosen because it is widely used and understood by several communities and is now comparable with ITRS at the centimetre level. In order to avoid the mistakes of the ADOS project, it was decided to fully involve African countries in the exercise. Heads of NMOs (National Mapping Organizations) feature prominently at various levels of the project. African participation is further assured by the direct involvement of the regional centres namely:

Regional Centre for Mapping of Resources for Development (RCMRD) representing Eastern and Southern Africa; Regional Centre for Training in Aerospace Surveys (RECTAS) representing French and English speaking countries of West Africa; l'Organization Africaine de Cartographie et de Teledetection (OACT) representing the Arab speaking countries of Northern Africa.

The project is to be implemented in sub-regional modules, namely Southern Africa Reference Frame (SAFREF), Eastern Africa Reference Frame (EAFREF), Northern Africa Reference Frame (NAFREF), Western Africa Reference Frame (WAFREF) and Central Africa Reference Frame (CAFREF) representing South, East, North, West and Central Africa sub-regions respectively. According to RCMRD, GPS observations will be carried out on selected existing control points in each sub-region. There will also be a number of permanent observing stations in each country which will be tied to the IGS (International GPS Service) permanent stations. Subsequently, during the computation, these points and the rest will be processed with relationship to the IGS stations, which are on WGS 84 datum. This means that the sub-regional network will now be in WGS 84 datum. Following the completion of the sub-regional networks, an analysis will be carried out to establish a continental geodetic datum tied to WGS 84. Transformation parameters will then be computed for use in the transformation of the national geodetic control networks and other geospatial databases.

4. SUMMARY

The New Partnership for Africa's Development is trying to address the social, economic and political development of African countries in a holistic, coherent and integrated manner. The development of regional infrastructures are amongst the priority areas of intervention outlined by NEPAD to enable it achieve its objectives. Infrastructures exist in space and surveying is invariably required to establish their positions. This information on their positions is necessary for the planning and execution of the associated projects. Further demands may be made on surveying in the case of cross-border infrastructures. This is because such projects may involve countries whose geodetic systems are based on different geodetic datums. Arrangements must therefore be put in place for transforming these different datums into one unified datum. The ultimate solution to this worrisome issue is to establish one geodetic reference system for the whole of Africa. This matter is being vigorously pursued through the AFREF project.

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BIOGRAPHICAL NOTES

Eugene Onyeka holds a BSc degree of the University of Nigeria in Surveying (1975). He also holds a MSc degree in Land Surveying (Photogrammetry Option) of Ahmadu Bello University (1983). He taught surveying for about seven years at Kwara State College of Technology, Ilorin before joining Home Construction and Dredging (Nig) Ltd. as the Chief Surveyor. In 1985 he became a member of American Society for Photogrammetry and Remote Sensing. On obtaining his Surveyor's Licence in 1986 he commenced a professional surveying practice focussed on cadastral surveys. In 1992 he joined the Academic staff of Enugu State University of Science and Technology. In November 2005 he returned from a two-year leave at Nigeria's Centre for Geodesy and Geodynamics.

Mr Onyeka is currently the Treasurer of Geoinformation Society of Nigeria. In August 2001 he was elevated to the status of Fellow of the Nigerian Institution of Surveyors. He serves on the Editorial Board of the Nigerian Journal of Surveying and Geoinformatics. He also served on the Anambra State Urban Development Board and on the National Technical Committee on Earthquake Phenomena. The combination of academic and practice backgrounds has positively influenced his research efforts. His publications include:

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