Roseires Dam Heightening Construction Surveys

Russell Tiesler, Australia

SUMMARY

The Roseires Dam Heightening Project (RDHP) is located near the town of Ad Damazin on the Blue Nile River in the south east of the Sudan, approximately 100 km downstream from the Ethiopian border, up to which the storage extends. The project was designed as a two stage project with the first stage being completed in 1967. That stage comprised a central concrete buttress dam one kilometre in length with integral spillway, deep sluice gates, power station and flanking earthen embankments of eight and four kilometres length. The second stage is to raise the dam by ten metres, with a total crest length approaching twenty five kilometres.

Each of these investigation and construction phases contained geodetic control and engineering survey activities and the aim of this paper is to both assess the historic surveying activities and detail the current state of the survey control during the mobilisation phase of the current contract.

The first stage was constructed in the pre-EDM era and control surveys were based on geodetic triangulation but in an as yet unidentified and apparently local coordinate system. No detailed survey data from that period was available. Some control stations were found with coordinates in the unidentified system. All second stage construction drawings had been produced in that same system but no relationships to national or international grid systems were available.

Transformation parameters (horizontal and vertical) were derived between the "old system", the current Sudan National and Irrigation Department Survey datums and WGS84 datum to permit the use of online solutions for GPS from free-to-net-services such as the Australian Government AUSPOS facility. Such transformations were used to convert "old system" drawings to current reference systems to enable real-time solutions for construction surveys based on RTK GPS and subsequent incorporation of the project into the Sudan National Survey and recently adopted Sudan Irrigation horizontal and vertical reference systems.

This paper covers the surveying activities during the mobilisation in 2008/2009 for construction of the second stage when the author was deployed on contract as Chief Surveyor for the Consulting Engineers, the Snowy Mountains Engineering Corporation (SMEC). These activities included establishment of a survey control network, coordination of Client, Consultant and Contractor's surveying staff, installation of Quality Assurance procedures and establishment of an ongoing training program for inadequately trained staff. A brief overview is given of working conditions relating to climatic, cultural diversity and security circumstances as well as capabilities of local and contract staff.

Roseires Dam Heightening Construction Surveys

Russell Tiesler, Australia

1. INTRODUCTION

The Roseires Dam Heightening Project (RDHP) is located near the town of Ad Damazin on the Blue Nile River in the south east of the Sudan, approximately 500 km from the capital city of Khartoum and 100 km downstream from the Ethiopian border.

The project was designed as a two stage project with the first stage being completed in 1967. This stage comprised a central concrete buttress dam one kilometre in length across the Blue Nile River at the Roseires Rapids with adjoining earthen embankments of eight and four kilometres length on the western and eastern abutments respectively. The concrete dam included a set of deep sluice gates, located in the eastern primary channel through the rapids; and a power station with adjacent spillway located in the western wing of the wall, both discharging into the secondary channel through the rapids. This secondary channel also served as the diversion channel during construction of the eastern wing containing the deep sluice gates.

The second stage was designed for construction at a later date after the first stage was in operation and with minimal disruption to that operation. This second stage would raise the dam and the top water level by ten metres, with the earthen embankments now extending from the heightened concrete wall distances of over fifteen and eight kilometres west and east respectively, producing a total crest length approaching twenty five kilometres. The existing deep sluice gates, spillway and power station turbines were to be retained as they had originally been designed to serve the heightened dam.

Construction of the second stage commenced at the start of the 1990's with the placement of some four kilometres of materials at the abutment of the heightened western earthen embankment. Construction then ceased during regional conflict and investigations into continuing the project recommenced in the 2004/2005 dry season. Investigations and preparatory studies continued with the aim to mobilise construction activities in the 2008/2009 dry season. These studies included detailed investigation into both resources required for the construction and an assessment of major maintenance requirements for the existing installation. This maintenance was to be incorporated within the new construction project.

Each of these investigation and construction phases contained geodetic control and engineering survey activities and the aim of this paper is to both assess the historic surveying activities and detail the current state of the survey control during the mobilisation phase of the current contract.

This paper covers the mobilisation period during which the author was deployed on contract as Chief Surveyor for the Consulting Engineers, the Snowy Mountains Engineering Corporation (SMEC), on the project. That is, from 04 August 2008 to 16 March 2009.

At the commencement of the project there were available onsite only three official sources of survey information. These were:

1. A set of current SMEC Contract drawings which had been sourced from the 1990/1991 drawings produced by Sir Alexander Gibb. These drawings provided coordinates for the main reference axis points for both the earth embankments and the concrete dam and four control stations for the concrete dam (albeit with errors- see 3.2). All coordinates and heights were in the original project horizontal and vertical reference systems.

2. A preliminary geodetic survey report provided by the Institut Geographique National (IGN) of France. IGN is the consultant contracted to the Dam Implementation Unit (DIU) of the Sudan Government for the purpose of establishing a nationwide geodetic framework for all hydro-development projects. This report contained a set of horizontal coordinates for eight control stations (albeit with errors - see 2.2.11) and elevations for the three of those stations the closest to the concrete dam wall. All values were in the new horizontal and vertical reference systems recently adopted by DIU.

3. A set of 1967 As-Built drawings produced by Sir Alexander Gibb & Partners (SAG) for the concrete dam and appurtenant structures. These provided positional information for some of the main features on the concrete dam and location of the deformation monitoring survey stations.

The relevance and useability of each of these sets of drawings will be analysed in section 3.2 on Horizontal Datum Connection. Included in the analysis is information subsequently obtained from various other sources during the months covered by this report.

2. History of Surveying in the Damazin Region

2.1 Description of Horizontal and Vertical Datums

Prior to reading this report's analysis of the various surveys, it is essential to understand the various datums used for both horizontal (East-North coordinates) and vertical (Height or Elevation) definition of control stations and the physical features of the structures of the project.

2.1.1 Horizontal

There are at least four different horizontal datums involved:

1. The "OLD SYSTEM" upon which the original construction as-built and deformation surveys, and the 1990's stage 2 construction commencement, were both based. This system is noted on the 1990/1991 drawings of Sir Alexander Gibb as being the Standard Survey Grid of Sudan. To this date the definition of this datum is yet to be determined and therefore no standard geodetic mathematical processes can be used to transform values from this system into the new system being implemented by DIU. This "OLD SYSTEM" coordinate system was perpetuated in the 2007 Contract Drawings produced by SMEC.

2. The current conventional global reference system used for Global Positioning System (GPS) surveying is known as WGS84 and is a geocentric system using the WGS84 ellipsoidal definition parameters. Current global free internet services which are available for processing geodetic standard survey data produce solutions for which the resultant WGS84 coordinates give a position for the observing station at the epoch of observation. These can then be transformed into whichever system the user desires.

3. The Sudan Surveying Authority's current standard survey grid for the national geodetic network is the ADINDAN Datum. It is based on the Clarke 1880 ellipsoid, a non-geocentric datum whose origin of axes is displaced approximately 260 m from the geocentre and has equatorial radius and flattening different to current geocentric ellipsoids. The effect of this difference is to cause a shift in ground coordinates of approximately 220 metres in a NNE direction compared with WGS84. The Adindan Datum is currently being used for the irrigation projects which will be connected to the RDHP.

4. The new reference system being adopted by the Dam Implementation Unit of the Government of Sudan is entitled DIUREF2007. Whilst it, like WGS84, is geocentric, it is different to WGS84 in that it is based on the GRS80 ellipsoidal parameters rather than the WGS84 definition and is fixed at epoch 2005.0. The difference in flattening ($\Delta 1/f = 5x10^{-3}$ ppm) between the two geocentric reference ellipsoids is insignificant at the latitude of the project and can be ignored. The differences in coordinates between a real time position in WGS84, as obtained at epoch of observation from conventional GPS, and those of the DUIREF2007, caused by plate tectonic motion (~ 3 cm/year), is currently insignificant in respect to the earthen embankment surveys. However, for precise control surveys in the future, it will be necessary to rotate those future station solutions back to the epoch of DIUREF2007 and then work with differential GPS methodology using the rotated coordinates of those new control stations.

5. There was possibly a fifth datum used in geodetic surveys in the RDHP region. It is not known what datum was used for the original geodetic triangulation surveys conducted in 1952. However, as the current national network is still using the Clark 1880 spheroid, it is reasonable to speculate that the 1952 surveys used the same datum. The Sir Alexander Gibb feasibility report of 1954 stated that the 1952 survey was used for the control of the feasibility study. However, the difference between the RDHP "OLD SYSTEM" coordinates and what could be expected from a national geodetic network of that era is very large, exceeding 45 Km in Eastings. So it is probable that the RDHP "OLD SYSTEM" coordinates were not taken from the 1952 national network but were based on an arbitrary local datum.

2.1.2 Vertical

There are two different vertical datums involved:

1.The Irrigation Datum (ID), upon which the original construction as-built and deformation surveys, the 1990's stage 2 construction commencement and all subsequent surveys prior to the IGN project, were all based. This vertical datum (also known as the Khartoum Datum) was perpetuated in the 2007 Contract Drawings produced by SMEC.

2. The Alexandria Datum (AD), which is now the national height datum, has been adopted by DIU for all hydro works within the Sudan. The use of the Alexandria Datum now unifies the hydrological studies of the Nile River systems from the source to the sea.

2.2 Horizontal and Vertical Control Surveys

The region has, during the last six decades, been subjected to multiple surveys, both geodetic and civil engineering construction, using a variety of reference systems based on varying horizontal and vertical datums and various technologies. Due to a paucity of available records of many of these previous surveys, final analysis and correlation of data between these systems is not yet complete.

Each of these surveys and drawings will be examined separately and then conjointly to explain the current knowledge of each and their useability in relation to the RDHP. The examinations will include details such as methods used for observations and data analysis, datums adopted, reliability and shortcomings in current knowledge in relation to correlating the various surveys.

The correlation is necessary to be able to combine the surveys from the 1960's as-built and deformation surveys with the current surveys of the existing structure for determination of the long-term deformation and for the control of the construction of the extension to the existing structures. It is only after correlation of all the relevant surveys that validation of the current contract construction drawings can be performed. Partial validation has been carried out and some errors have been found in both existing surveys and contract drawings.

The surveys and documents containing survey information in the region are summarised in the following table:

Project	Type of Survey	Year	Datum	Organis-ation
Sudan National Trigonometric and Height Datum Determination Blue Nile Region				
	Geodetic Triangulation	1952	Horizontal : Unknown	SSD
	Geometric Levelling	< 1954	Vertical : Irrigation (Khartoum)	UNK
Roseires Dam Stage 1 Construction				
	Engineering Construction Surveys	1961–1967	Horiz: OLD SYSTEM Vertical : Irrigation	SAG
	As-Built & Deformation Survey Drawings	1967	Horiz: OLD SYSTEM Vert: Irrigation	SAG
Roseires Dam Stage 2 Construction First commencement				
	Engineering Construction	1990–1991	Horiz: OLD SYSTEM Vert: Irrigation	UNK
	GPS Control Survey	1994	Horiz: OLD SYSTEM Vert: Irrigation	SSD

Roseires Dam Stage 2 Construction Second commencement				
	Terrestrial/GPS Control Survey	2004–2005	Horiz: OLD SYSTEM Vert: Irrigation	ACP
	GPS RTK Digital Terrain Model Survey	2006–2007	Horiz: OLD SYSTEM Vert: Irrigation	ACP
DIU National Network Datum determination				
	GPS Geodetic Survey	2007	Horiz: DIUREF2007	IGN
	Precise Geometric Levelling	2007–2008	Vert: Alexandria	IGN
Roseires Dam Stage 2 Construction 2008 season				
	GPS Control Survey	2008	Horiz: DIUREF2007	IGN
	Construction Contract Drawings	2008	Horiz: OLD SYSTEM Vert: Irrigation	SMEC
	Terrestrial/GPS Geodetic Survey	2008–2009	Horiz: WGS84 & DIUREF2007, Vert: Alexandria	SMEC

Table 1 – Surveys and Documents relevant to the Roseires Dam Heightening Project

2.2.1 National Trigonometric Survey 1952

The first geodetic control in the region was conducted as part of a national geodetic triangulation network. The Blue Nile section of the network was observed in 1952 with stations being located at approximately 15-20 kilometre spacings. Stations were located on existing kopjes where they arose above the plains; and where none existed in suitable locations, observations were conducted using triangulation observation towers erected over stations constructed on the level plains. From this network no original documentation has been able to be obtained.

Coordinates were obtained from the Sudan Survey Authority for the four stations which are located in the proximity of the RDHP (887 J. MABA KIRMA, 888 J. GARGADA, 889 DAMAZIN and 890 AZZAZA), and other adjacent stations both upstream and downstream of the project (see Figure 1). The coordinates of these stations are expressed in terms of the current national survey system, the Adindan Datum, based on the Clark 1880 spheroid. It is not yet known upon which datum the original network was based.

At this time it is relevant to point out that the coordinates used in the 1960’s stage one construction, the 1990’s construction session, and the 2004-2005 and 2006-2007 surveys conducted by ACP are in a coordinate system whose origin is yet to be determined. It is speculated that they probably were not in whatever datum was used for the original 1952 geodetic survey but the relationship between that datum and the Adindan Datum has not yet been determined by this report.

A GPS network geodetic survey was conducted incorporating the above mentioned four trigonometrical stations and three of the RDHP primary control network stations (A0, C4, and DIU1). The purpose of this survey was to provide a direct connection between the RDHP project (in the DIUREF2007 system) and the national system (ADINDAN).

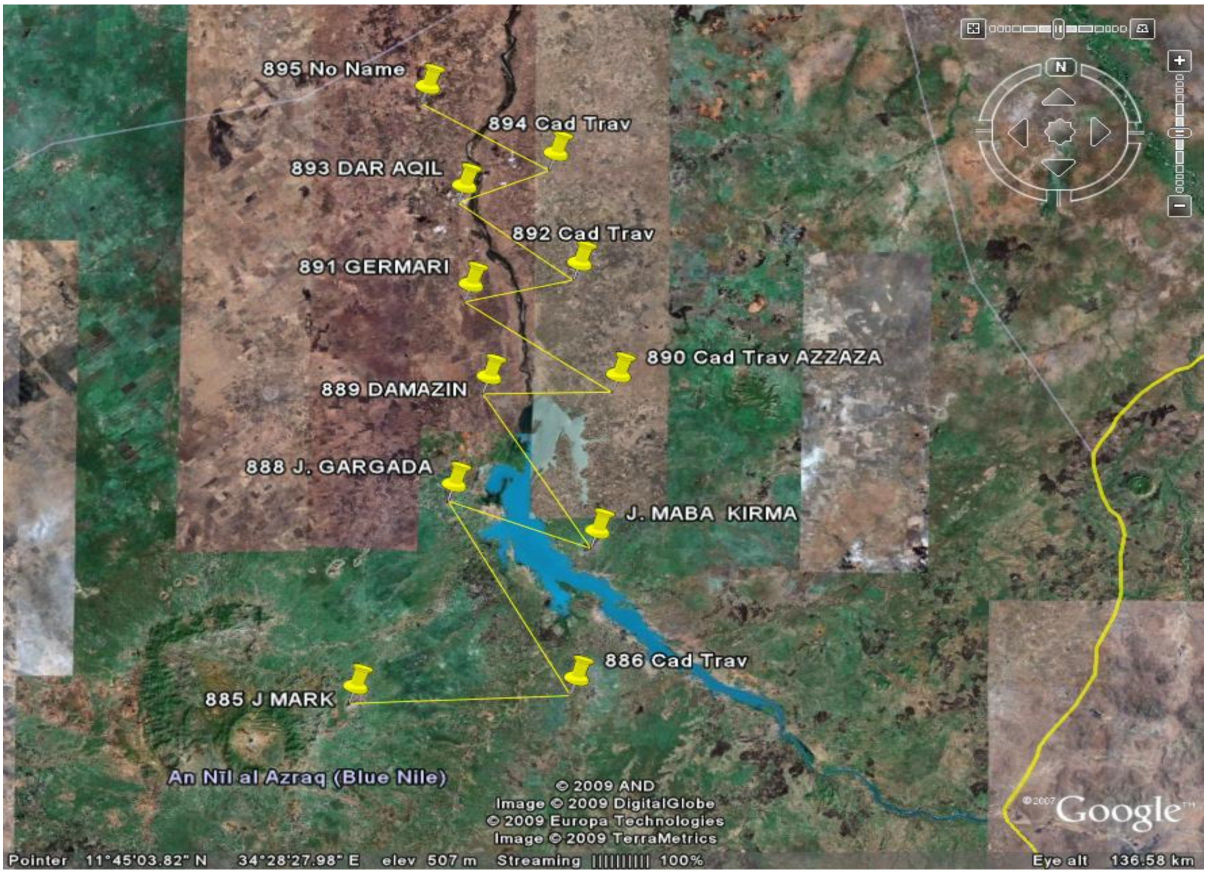

Figure 1 – National Trigonometrical Stations in the Damazin region

This connection was necessary because the irrigation projects being conducted by Lahmeyer International are all in the ADINDAN system and a precise connection to RDHP relevant features (canal headworks, hydrostatic modelling and storage data) was required.

Up to that time the only connection of the project to any national network was via the coordinates provided by the IGN preliminary survey report of 18 May 2008 based on IGN's determination of the DIUREF2007. Because that report contained erroneous information (see 2.2.11) an independent connection was required to validate the IGN data. The DIU national network project DIUREF2007 produced a connection to the ADINDAN system with a stated accuracy of only 1-2 metres. And that connection is in excess of 500 kilometres distant which fails to meet the basic survey criteria of working only within control limits.

The results of the survey conducted on 31 January 2009 have yet to be fully analysed. Of the four stations only two (J. Gargada and Azzaza) had the original survey monuments still in an undisturbed condition.

The pillar on J. Maba (known locally as J. Kirma) was completely destroyed and its location could only be estimated to within 0.5 metre. However, a recovery mark (RM) was located to the northwest of the primary station and that also was observed. Future liaison with the SSA to determine the eccentricity of the RM should yield a satisfactory solution for this station.

Having a satisfactory solution for this third station should yield a LSQ solution but with only one degree of freedom. It is advisable to locate and occupy one of the Damazin station's RM's to provide a four station solution, thus providing two degrees of freedom. Should Damazin no longer have any surviving ground marks, then either station 886 or 891 (see Figure 1) needs to be occupied in lieu of Damazin station.

2.2.2 Blue Nile Levelling Survey – Irrigation (Khartoum) Datum

No details are available for this survey. There is no indication as to the Class or Order of the survey to give an indication as to the methodology used to conduct the survey. The only conclusions to be reached are that it preceded the construction of the Phase 1 project and that it extended level control from the Khartoum origin up to the Ethiopian border past the gauging station, El Deim, located near the upper end of the existing storage.

2.2.3 Roseires Dam Stage 1 Construction Survey

There are no records of control surveys available. Should such records be discovered then a definite transformation between the "OLD SYSTEM" coordinates and the DIUREF2007 and ADINDAN systems could then be performed. The investigation and search conducted at the DIU archive in Khartoum on 24 December 2008 failed to yield any survey records. An alternative source for enquiries would be the Phase 1 consultants – Sir Alexander Gibb and Partners (SAG) who merged with Jacobs Engineering Group in 2001.

2.2.4 Roseires Stage Stage 1 Drawings of Construction As-Built and Deformation Surveys

A set of 1967 As-Built drawings were produced by Sir Alexander Gibb for the concrete dam and appurtenant structures. These drawings contained no information as to the origin of the horizontal survey grid system used in the Phase 1 construction but did contain elevations of features on the concrete dam. As these elevations were in the Irrigation Datum and could be readily accessed it was therefore possible to re-observe these points in the newly adopted Alexandra Datum and hence determine a difference between the two datums.

It is important to remember that this datum shift is only applicable to the features on the RDHP and not nationwide. The difference determination is dependant upon the precisions with which both the original elevations for Phase 1 were transferred from Khartoum and the new values for the control stations were determined by IGN.

Field observations determined the difference between the old (ID) and new (AD) vertical datums. An analysis of 35 points on the dam crest determined the local difference to a precision of 0.005 metres at the one sigma level.

2.2.5 Roseires Dam Stage 2 – 1990/1991 Engineering Construction Drawings

These drawings contained coordinates for major points on the dam reference axis and coordinates for control stations of the concrete dam. However, the only indication of the reference system for those coordinates was a statement that the coordinates are based on the 'Standard Survey Grid of Sudan". This is insufficient to determine the origin of a system which is 45 kilometres out of synchronisation with the current conventional global and Sudan national systems.

2.2.6 Roseires Dam Stage 2 Construction – 1994 Embankment Dam Control Survey

There are no details for this survey. The only information is a fax from Sir Alexander Gibb to Coyne et Bellier dated 11th December 1994. This fax provided coordinates for points along both earthen embankments as well as at the concrete dam site. A copy of this fax was provided to ACP in 2004 for their 2004-2005 preliminary control survey.

2.2.7 Roseires Dam Stage Construction - 2004/2005 Preliminary Control Survey

This survey was conducted by Associated Consultants and Partners Ltd (ACP) under contract to SMEC during the 2004-2005 dry season. The complete set of result documents were subsequently delivered to SMEC but were not available at the project site in 2008 and can not be located.

An unofficial extract (multi generation photocopy- source unidentified) of the summary of the 2004-2005 survey was obtained which gave the results of the connection between the concrete dam control station C4, a 1994 GPS survey (see 2.2.6), and a single concrete ground mark A0 (see Figure 2 – Station A0 Left abutment), located above the abutment of the Left Embankment. The coordinates for station A0 had been obtained from a separate source. The 2004 traverse differences to the 1994 survey indicated a significant rotation but the individual discrepancies had a randomness which indicated that the 1994 GPS survey precision was poor. But without having the actual results from the GPS survey, including the transformation from the GPS global solution to the local system, to assess its quality, this supposition could not be verified.

Interviews on 24 December 2008 with the persons who conducted the surveys in 2004/2005 and 2007, current and previous employees of ACP, revealed that during the 2004-2005 and 2007 surveys, ACP field teams also discovered the existence of concrete ground marks located at the major definition points of the earthen embankment axis. However, no details of either ACP's, or any previous organisations', surveys of those embankment axis marks have been obtained except for the station A0 at the extremity of the western embankment. This station A0 does not appear on either the 1990 Sir Alexander Gibb or the 2007 SMEC drawings and is critical to the orientation of the transformation between "OLD SYSTEM" and DIUREF2007. It is therefore essential that the full report of the ACP survey be obtained to validate the usage of station A0.

2.2.8 Roseires Dam Stage 2 Construction – 2006/2007 GPS RTK DTM Survey

This survey was conducted by ACP using GPS Real Time Kinematic methodology.
The control points used for this Digital Terrain Model survey were the same stations which ACP surveyed in their 2004-2005 contract with the coordinates still in the OLD SYSTEM. ACP therefore performed a site calibration with the GPS equipment to transform their observations from the global solution in WGS84 to the OLD SYSTEM coordinates.

Whilst all results of this survey are presented in the OLD SYSTEM, the report included a set of transformation parameters between their observed GPS results in WGS84 and the 1990's OLD SYSTEM. The determined transformation parameters (Scale, Rotation and Translation) agree to within acceptable limits to those determined by the SMEC verification geodetic control survey.

2.2.9 DIU National Network Datum Determination – IGN 2007 GPS Geodetic Survey

The DIU reference system to be adopted for all irrigation works in the Sudan is entitled DIUREF2007 and has been developed by the Institute Geodesique Nationale (IGN) of France. It is, unlike WGS84, a static system which has its reference epoch at 2005.0 and no provision for crustal plate tectonic motion. This is, in itself, not a significant problem because all of the Sudan is within a stable plate, and as long as all survey work is referenced back to a known station within the Sudan. A global GPS solution in WGS84 is not directly connectable without applying plate motion vectors from epoch of observation back to epoch 2005.0. Use of the DIUREF2007 in conjunction with WGS84 must be treated with caution. It is conventional in titling a system to use the epoch of the solution in the name and not the year in which it was produced. Here we have the potential for a two year error in applying plate motion velocity vectors.

The main concern with the use in the RDHP of the DIUREF2007 values supplied by IGN is one of precision. The DIUREF2007 – ADINDAN transformation parameters were derived from a set of 14 1st Order stations predominantly in the northern part of the Sudan. The closest of those to Damazin is 110 kilometres to the north and the furthermost another 700 kilometres north. Thus RDHP is operating outside the perimeter of that adjustment. The IGN report on the DIUREF2007 solution states an estimated precision at the 95% confidence (2σ) of 1-2 metres. Extrapolating outside that control network would continue to degrade the precision of that solution.

For the RDHP region a new transformation needs to be determined for connection between DIUREF2007 and ADINDAN. This is best done by occupying trigonometrical stations which surround the RDHP and for which there exist ADINDAN coordinates. Such stations must be occupied in the same observation sessions as the primary control stations for the RDHP.

2.2.10 DIU National Network Datum Determination – IGN 2007-2008 Precise Geometric Levelling

Prior to the IGN levelling surveys of 2007-2008, all elevations used in surveys on the project were based on the Irrigation Datum which was also sometimes called the Khartoum Datum because of the location of its origin.

In 2007 IGN, concurrent with producing the DIUREF2007 horizontal datum network, conducted Precise Level traverses across the region to implement the newly adopted vertical datum chosen for all the DIU projects within the Sudan. The adopted datum is called the Alexandria Datum, being based on the mean sea level determination at Alexandria at the Nile River delta on the Mediterranean Sea. The advantage of adopting such a common datum is that all hydraulic management analysis of the river system from source to sea, and the dependent irrigation projects, can be integrated. This was not previously possible with varying datums in Egypt and the Sudan. This level network was extended southwards to connect three of the concrete dam monuments (C1, C2, and C4), as well as three of the embankment deformation monitoring stations (PR2, PR7, M28).

At the time of handover of IGN's preliminary geodetic control report (see 2.2.11), IGN supplied elevations for the RDHP control stations (C1, C2 & C4). No documentation was provided for the network from which these elevation values were derived, therefore no validation was possible.

2.2.11 Roseires Dam Stage 2 Construction – IGN 2008 GPS Control Survey

This control survey was conducted by IGN using GPS methodology. IGN produced a preliminary report which provided coordinates for the three concrete dam control stations (C1, C2, C4) and the west embankment station (A0), as well as three of the embankment deformation monitoring stations (PR2, PR7, M28). IGN also produced coordinates for what they assumed to be the other primary concrete dam station, C3, but erred in that they occupied a station 180 metres further downstream.

The provided coordinates are in both geocentric Cartesian (X,Y,Z) and DIUREF2007 projection UTM 36 (Easting, Northing). Also provided are the ADINDAN projection UTM 36 coordinates. As these have been transformed using the parameters determined from IGN's distant Northern Sudan network, they need to be verified by direct connection to ADINDAN coordinated national trigonometrical stations in the RDHP region.

IGN's preliminary report contains no details of the observation network, how these stations were connected to the DIUREF2007 system or the analysis from which the values it contains were derived. As well as containing an erroneously occupied and observed station, the report also erred in that it had all East and North coordinates transposed.

3. ROSEIRES DAM STAGE 2 CONSTRUCTION – SMEC GPS & TERRESTRIAL CONTROL SURVEYS

The first task in the current mobilisation was to verify the IGN horizontal coordinates from their GPS geodetic survey network and the elevations of their height reference stations. For the coordinates a GPS static geodetic survey was conducted over the seven (7) correct stations in the IGN report. The eighth station, incorrectly identified as C3, was ignored. For the elevations a Precise Level Traverse was conducted between the three IGN provided stations.

1.1 Horizontal Control Survey

Included in the GPS network were two additional stations. One was on an old concrete mark discovered in the proximity of the end of the proposed right embankment and later identified as a recovery mark for Dam Reference Axis point H (see Figure 3 – Station B0 Right abutment and Figure 4 – RDHP Primary Control Network). The other additional station was installed on the roof of the DIU Office in Damazin. Initially this station was located on the NW corner of the roof (DIU0) and later relocated up to the roof over the eastern stairwell (DIU1). The relocation was to give additional height and a 360^{o} clear horizon for the operation of a Real Time Kinematic (RTK) base station which could cover the complete project works areas. This RTK setup achieved coverage over all the works areas with a precision better than 0.02 m.

Results from the primary network observations were produced using the AUSPOS internet service provided by the geodesy department of Geoscience Australia, an Australian Government organisation. AUSPOS produces solutions which are in the WGS84 system at the epoch of observation.

Figure 2 – Station A0 Left abutment

Figure 3 – Station B0 Right abutment

As the RDHP observations were at the epoch of August 2008, in order to check the IGN values, it was necessary to rotate the results back to the epoch of the DIUREF2007 system, which was given as 2005.0. This was done using the NNR-NUVEL-1A tectonic plate velocity model and compared with the IGN values. Results indicated no significant discrepancies in the IGN reported values for the East and North coordinates. The GPS results also confirmed no gross errors in the elevations for the three provided stations (C1, C2 and C4).

3.2 Horizontal Datum Connection

To transform the values of coordinates on the construction drawings from OLD SYSTEM required locating original points for which OLD SYSTEM coordinates are known and observing their coordinates in the required new system. Using these common points, a set of Least Squares Solution (LSQ) transformation parameters was determined with which to transform all the other required points.

To perform a LSQ best fit requires sufficient common points to provide enough degrees of freedom (redundancy) such that the residual error vectors of the solution enable determination (and elimination) of erroneous sites and assessment of the overall precision of the final solution. As the resultant solution is based on physical points on the ground which had been previously place using the OLD SYSTEM, the final precision is dependant upon the accuracy of initial placement of those points. It should therefore not be used for transforming any points which are outside the perimeter of the area defined by the outer-most acceptable common points in the solution as the residual errors are enlarged as the solution is extrapolated outside the area of control.

The SMEC 2007 Construction Drawings provided coordinates for the main reference axis points for both the earth embankments (A, B & C for Left Bank and F, G & H for Right Bank) and the concrete dam (D & E), and four control stations for the concrete dam (C1, C2, C3 & C4). All coordinates and heights were in the original project horizontal and vertical reference systems. However, the coordinates of C1 contained a transcription error which was not resolved until the original SAG1990 drawings were obtained on 26 November 2008.

With the failure of C1 (SMEC) and C3 (IGN) there were only two common stations (C2 and C4) on which to perform a transformation. This is not enough for a LSQ solution and also they are only 600 metres apart and the extremities of the project extend up to 15 kilometres from them.

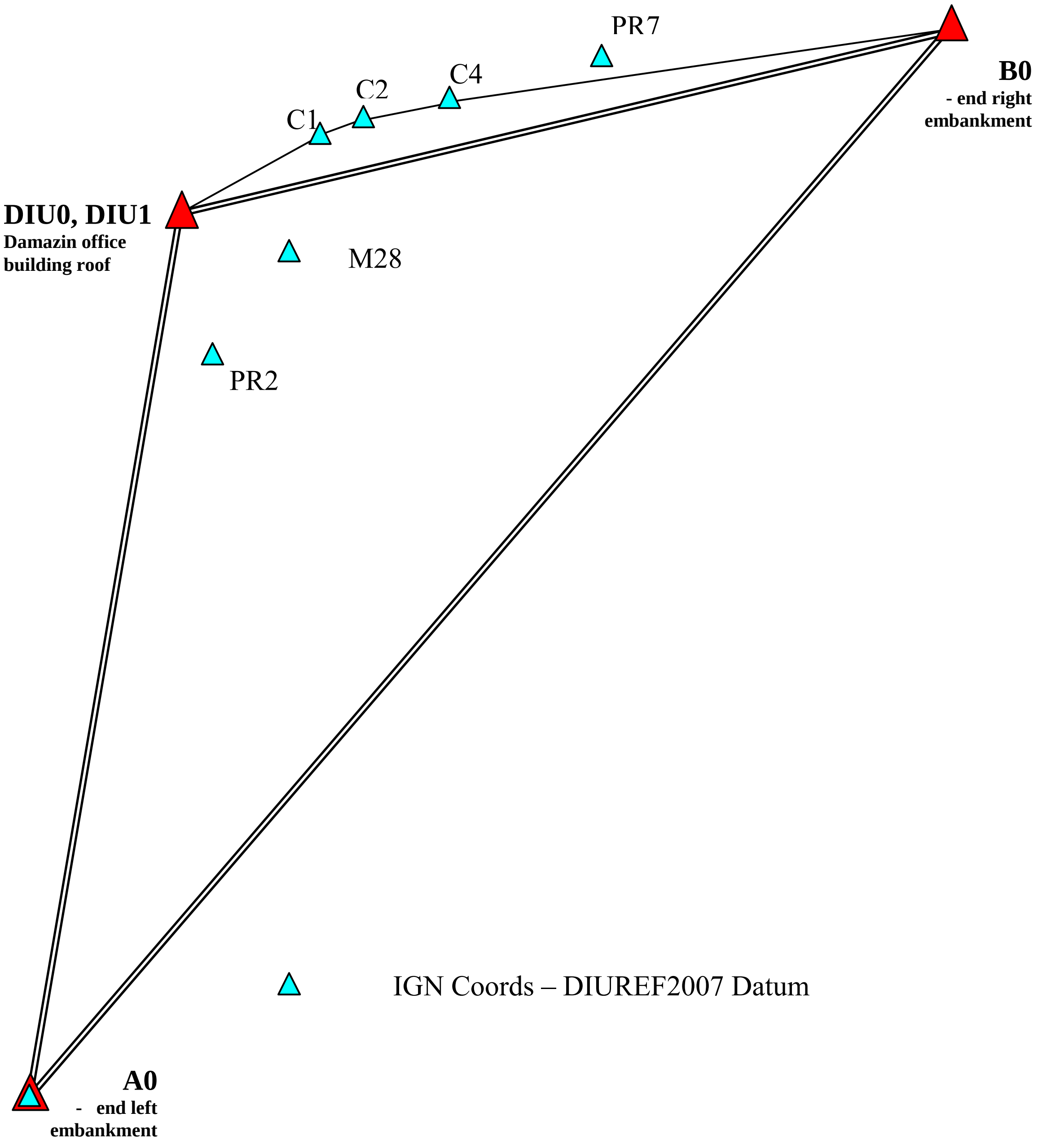

Figure 4 – RDHP Primary Control Network

Whilst IGN had values for A0 at the west end of the embankment, A0 did not occur on either SMEC 2007 or SAG 1990 drawings. Discovery of the ACP 2004-2005 survey report extract provided OLD SYSTEM coordinates for A0. This enabled an initial LSQ transformation solution to be achieved which replicated (to within useable limits) the transformation achieved by ACP in their surveys. Using the derived transformation parameters, SMEC surveyors were then able to locate the existing embankment point marks placed during the earlier construction phases and observe them.

Also by then, with the arrival of the SAG 1990 drawings, the error on the SMEC drawings of station C1 coordinates had been resolved and C1 could be included in the transformation which now included 14 dam reference axis points (10 Right Bank, 2 concrete dam, 2 Left Bank), A0 and the 3 concrete dam control stations C1, C2 and C4.

The final transformation was performed using A0, C1, C2, C4, F and F2; achieving a standard deviation of 0.02 metres. The remainder of the observed Right Bank stations exhibited a consistent swing of 50 seconds of arc, indicating an inconsistency between design and set out commencing at station F, the intersection point between the concrete dam and Right Bank earthen embankment reference axes. Therefore their coordinates in the OLD SYSTEM were revised and their observed values in DIUREF2007 were adopted for final design.

All embankment coordinates are ellipsoidal and are unaffected by varying elevations of terrain. The actual ground distances between points vary from distances computed from coordinates according to the elevation of those points above the ellipsoid. For RDHP at an elevation of 500 metres ASL, this difference is approximately 0.08 metres per kilometre.
For the embankments this is inconsequential, being less than 30% of the permitted tolerance for earthworks. Therefore embankment surveys will be conducted using RTK GPS or Total Stations with distances restricted to less than 300 metres.

However, for the concrete dam construction, such differences are outside tolerance. Accordingly, all concrete dam coordinates are to be produced at a working level commensurate with the structure.

3.3 Vertical Control

To validate the elevations for those stations to the precision required for their employment a Precise Level traverse was run between them via the concrete dam wall. This level traverse later provided the base for observing dam crest points for determining the difference between the two height datums, Alexandria (AD) and Irrigation (ID). The observed height differences compared with the IGN results were within required accuracies.

3.3.1 Vertical Datum Difference Determination

A Precise Level survey was observed between the height control stations and points on the dam crest identifiable on the drawings. A total of 35 points were observed, yielding a vertical connection between the two datums of 3.02 metres with a standard deviation of +/- 0.007 metres.

3.4 Concrete Dam Control Stations

The adopted working level is to be 485 metres (AD), the height of the existing crest. The working level coordinates will thus yield distances with a precision of 3 ppm. All control stations used for concrete dam works are to have coordinates derived from the project primary station C4 which is located downstream on the Right bank.

The stations C1 and C4 are currently in the proposed canal alignment corridors. The stations C3 and C2, being low and close to the wall, and with the 10 metre increase in the crest level, will produce very steep sightings to the crest works. Therefore all stations are to be relocated as per Figure 5. In March 2009 only the station C4 Relocation had been constructed.

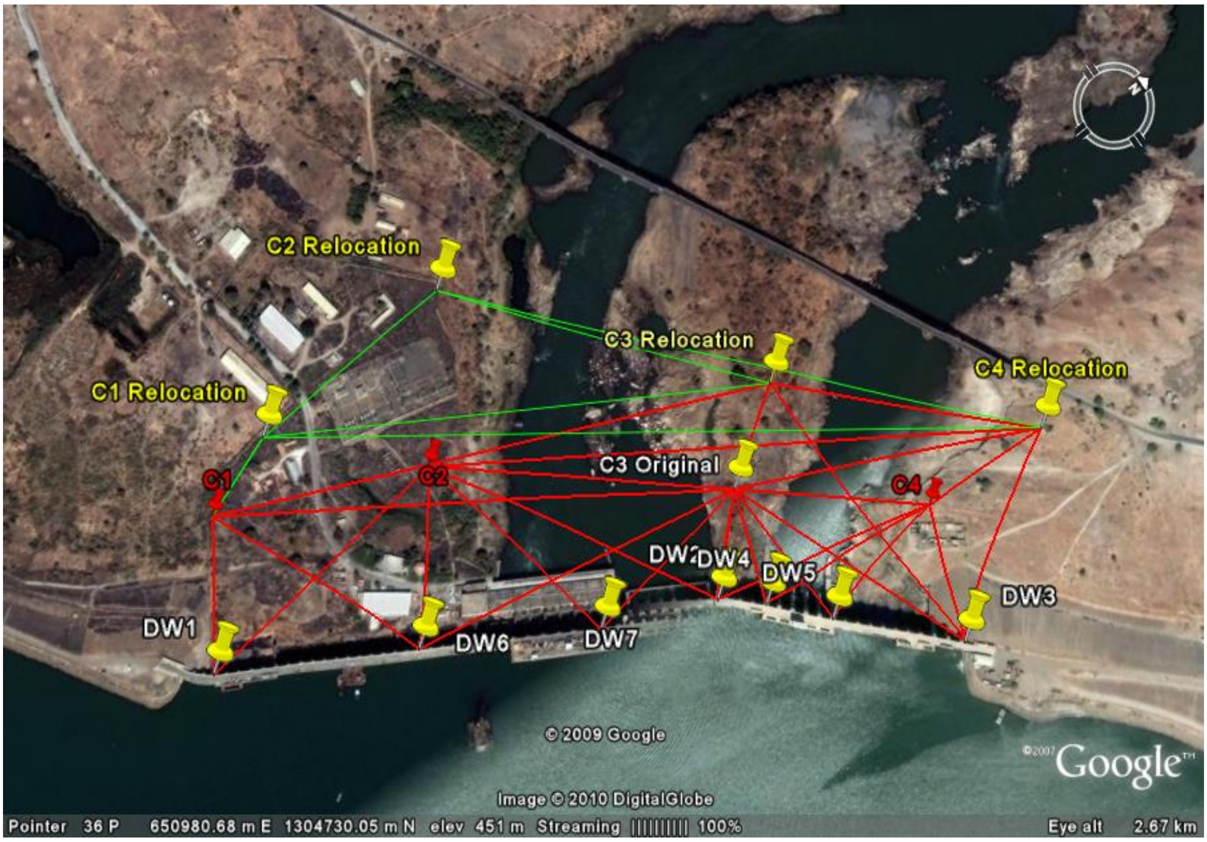

Figure 5 – Concrete Dam Control Stations

The network observations to produce Working Level (WL) coordinates for these stations have been completed for C1, C2, C3, C3 Relocation, C4 and C4 Relocation. Included in the network were seven (7) of the dam crest deformation monitoring pillars. These were incorporated to give depth to the network, determine the deformation since construction (no records of deformation surveys since 1967); and to provide stations from which to determine the dam reference axis by observing structural features.

4. SUMMARY

The results of the surveys and attendant transformations are contained within the RDHP survey reports and are the intellectual property of the Consultants, SMEC, and the Dams Implementation Unit of the Sudan Government.

The largest problem in relation to survey was the lack of historic data with which to link the previous and current activities. This required much archival research in various departments which had changed functions over the intervening five decades. This was exacerbated by the departure of the British in the 1960's and the reallocation of government departments in a new social order. A project such as this which involves constructing "add ons" to an existing large civil engineering structure has unique demands on precision and quality not normally encountered with the construction of a completely new project.

Other significant problems on this project were the lack of capable survey staff employed by the Contractor and the Contractor's unwillingness to comply with the Consultant's requests for both provision of survey staff with appropriate qualifications and construction of the required survey control station monuments. This required the establishment of a training program to raise the competency of the Contractor's survey staff and the installation and enforcement of comprehensive Quality Assurance procedures.

The environment, excessive humidity in the wet season and extreme temperatures and dust haze in the dry season, required constant monitoring of staff for both personnel well being, safety and quality of work performance.

The security of the project was initially maintained by a large presence of Sudan military (the dam being a strategically important structure) and later supplemented by an additional national police contingent of approximately 100 personnel during heightened rebel activities. There was also a UN detachment of approximately 1500 soldiers deployed in the area which contributed to the regional security and no significant incidents occurred during this period.

CONTACTS

Mr Russell TIESLER
Monaro Surveying Services
PO Box 4299
Hawker ACT 2614
AUSTRALIA
Tel. +61 2 6254 2619
Email: Tiesler_russ@yahoo.com