FIXING GIBE II – ENGINEER'S PERSPECTIVE

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The news of the most recent structural damage in a section of the tunnel that carries water to the Gibe II power plant has come as a crushing bad news for the Ethiopian people at-large. Due to the immense potential this particular project carries in alleviating the energy shortage that has thrown our cities and towns into darkness in most days, idled factories on 3-4 days per week, and cut down agro-industrial output, the pain caused by further delay will be deep and almost universal. To make matters worse, the prospect of another season of blackouts continues to disappoint Ethiopians of all walks of life as the promise of 480 Mega Watts of power remains unfulfilled until this is fixed or the 460 Mega Watts **Tana-Beles** goes online soon.

Why the single most important component of this project - the 26kms tunnel that brings the waters of **Gilgel Gibe River** to the power plant in the **Omo River** valley through a 500 meter pressure head - keeps on facing structural and geological problems has prompted serious discussion among the Ethiopian engineering community, particularly in the Diaspora. While there is deep respect for the track record of the contractor as well as the main consultant design engineers of this project in other relatively well-executed projects such as Gilgel Gibe I and Tana-Beles, the repeated nature of the problem has naturally inspired several questions regarding the severity of the technical problems. At this point, it is obvious that opinions on the extent of the problem do vary; but it is increasingly becoming clear, however, that there is enough evidence to suggest that there are key fundamental and consequential flaws that have resulted in repeated failures. It is important, therefore, to ask key and relevant questions and pursue their answers not only to understand the root causes of the problems but also to suggest remedial measures for this project of immense national importance.

We believe the following questions arise in connection with the repeated failures observed in the Gibe II project.

A) Engineering and Design Specific Problems

1) Are the structural problems with the tunnel caused by any of these: engineering design errors, equipment problems, wrong geological and geophysical assumptions?
2) Was the engineering design and construction of the tunnel independently reviewed by a third-party with no conflicts-of-interest?
3) What is the likelihood that the latest attempt will be the last fix needed? Will more problems occur again?
4) What are the contingency plans if it is determined that the tunnel will continue to have problems?
5) Has the seismicity of the area encompassing the Gilgel Gibe series of projects been considered? What are the risks associated with not considering seismicity if it is determined to be important?

B) Conception to Build-and-Deliver Process Related Problems

1) Are there systemic flaws in the project execution process itself starting from conception to build-and-deliver stages?
2) Are these project management problems limited to Gibe II project or are they also present in the other infrastructure projects as well?
3) Is there anything unique to the Gibe II Project that brought the problem to the forefront?

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4) Does the contractor's role in securing financing of the project introduce any element of risk?

As Ethiopian engineers who grew up in various parts of the country dreaming about the immense power engineering carries in transforming the Ethiopian society, we believe the present time is an interesting time as far as engineering is concerned. As things stand, a multitude of global factors and events such as monetary flow from the Diaspora, investment from China, India, Europe and Middle East, initiatives associated with UN's MDG (Millennium Development Goal) coupled with improved policies and relative peace continue to collide to create an optimum condition for the realization of consequential large-scale projects in the energy, transportation, and water supply sectors. We also do believe that there is sufficient evidence to suggest that such conducive environment will continue to prevail in the foreseeable future despite some hiccups along the way. It is, therefore, our most passionate wish to see these large-scale projects completed on time and help improve the lives of our people.

However, while excited and appreciative of these developments – particularly the immense contributions the main contractor Salini Costruttori is making in Ethiopia now -, we are, nonetheless, concerned that the critical flaws in current practices for such large-scale projects will ultimately create a particularly damaging and costly scenario leaving a trail of failed projects. This concern forms the basis of the inspiration for this article where we investigate the systemic engineering and project management problems and suggest recommended fixes. As practicing engineers, we limit our discussion in this article to strictly professional opinions, particularly to the specific example of Gibe II project. Our wish is to see policy-makers use the findings and recommendations of this report to initiate fixes to these problems that affect projects of immense national importance.

I. BRIEF OVERVIEW OF THE GIBE II PROJECT

Over the past few years, the Gibe II project (as well as Gibe III) have been described numerous times in several places. To avoid repetition, in this article, however, we focus on the engineering, project management and the geography aspects of the project.

Geography of the Project

The story of Gibe II project starts where the 185 Mega Watts Gilgel Gibe I project ends. The **Gilgel Gibe River** which hails from an area near Jimma and flows from south to north forms the basis for Gilgel Gibe I dam. After the dam, the river flows for another 25 kilometers further north. Right around the **Gibe Bridge** on the Addis-Jimma road, **Gilgel Gibe** merges with the north-south flowing **bigger Gibe River** that originates from the watersheds of the Wollega highlands as well as Butajira highlands. The combined river then continues to flow southward and eventually drains to **Lake Turkana** in Kenya. Downstream of the Gibe Bridge, the combined river has been traditionally called **Omo** and flows all the way to **Lake Turkana** in Kenya forming a natural boundary between the Sodo and Gamo Gofa regions on the East and the Jimma and Kaffa regions on the west. Arguably, the combined river continues to be called **Gibe River** until it meets the **Gojeb River** further downstream after which it assumes the name of proper Omo River.

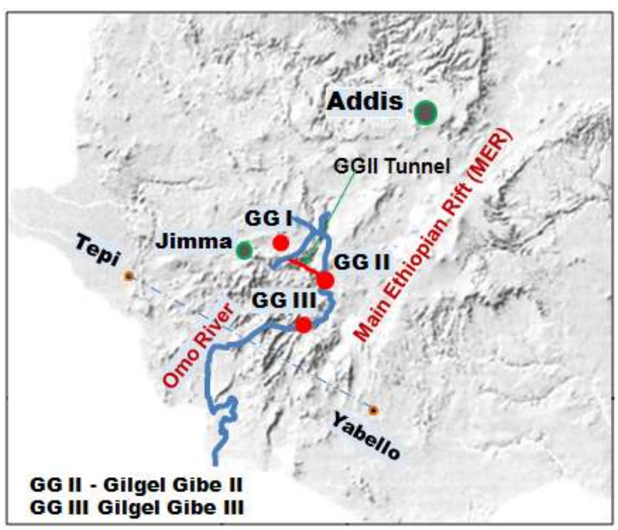

Figure 1. The geography of Gibe II project.

As shown in Figure 1, Gibe II project involves bypassing the north-ward course of the Gilgel Gibe River by 100kms and forcing part of its water to flow through a tunnel across a hilly ridge and meeting the Omo River in a direct westerly direction. This 26kilometer tunnel across the **Fofa** hill that could be considered as a short-cut is what forms the most important component of this project. Taken by its face value, this core component is an attractive idea and, as discussed below, was originally pitched by the contractor and its design engineering partner.

The planned 1.4 Giga Watts Gibe III (which is actually under construction now) and 1.5 Giga Watts Gibe IV are located another 125 kilometers and 250 kilometers, respectively, downstream of Omo River as shown in Figure 1. It is interesting to note that while Gibe II, III, and IV are all technically on the Omo River, these projects continue to be associated with Gilgel Gibe and Gibe Rivers.

Genesis of the Project

As the company that brought Gilgel Gibe I project to a fruitful completion and even helping in its financing, the Rome-based Italian construction company, Salini Costruttori S.p.a., was in a opportune position to not only propose the Gibe II project to the Ethiopian government at the highest level; but also to offer to execute it. Salini Costruttori S.p.a. is a multi-billion dollar family-owned business [1] and is typically the contractor wing of a professional alliance that involves the respectable engineering design consulting company, Studio Ing. G. Pietrangeli S.r.l. of Rome, Italy [2]. This design firm is also a family-owned business and was founded in 1964 by Mr. Giorgio Pietrangeli [2].

The story of Salini Costruttori S.p.a. and Studio G. Pietrangeli's involvement in construction in Ethiopia dates as far back as 1969/1970 during Emperor Haile Selassie's time where they built the **Legedadi** water supply dam which is still operational after 40 years [2]. Mr. Giorgio Pietrangeli and his son, Mr. Antonio Pietrangeli are the engineers-of-record for all the Gibe series of projects.

Like most large-scale engineering projects around the world such as the Golden Gate and Brooklyn bridges in the US, and the Aswan Dam in Egypt, important projects in Ethiopia also have a largely personal side to them. Mr. Giorgio Pietrangeli has a genuine interest and love for Ethiopia dating back to the Emperor's time and had established close personal relationships with the Emperor himself and the subsequent political leaders[3]. As most Ethiopians know, despite the two wars (Adwa and the 1935-41 occupation), there are many indications that Ethiopia and Italy have – over the years - maintained close and productive relationship that have resulted in numerous infrastructure projects funded and built by Italian firms and government. Mainly due to the passion and genuine desire to help that they bring to these projects – some of which are located in the remotest part of the country even most Ethiopian avoid - the Italians have earned the respect and admiration of the engineering and construction community as well as policy-makers.

Figure 2. G. Pietrangeli's respected association with Ethiopia dates back to Emperor Haile Selassie's time. Mr. G. Pietrangeli is shown with the Emperor during the inauguration of Legedadi dam in 1970. Courtesy: SGP.

Along these lines, in addition to the Legedadi water supply dam project, Studio G. Pietrangeli was also involved in several infrastructure projects such as the original **Tana-Beles** Agro-industrial Project started during the Dergue period[4] and the **Dire Dawa** water supply Dam. Salini's track record as well as the offer to help bring Italian government financing, we believe, was very important in convincing the political leaders of the country at the highest level to offer the project to the Salini-Pietrangeli group with no-bid. As it turns out, this '*no-bid'* award constitutes a very important aspect of the project that has proven to have fundamental consequences in this particular project.

[3] *This was confirmed by engineer colleagues of the authors who have knowledge of the events.*

[4] *The original* ***Tana-Beles Agro-Industrial*** *project started in 1988 during the Dergue's time and involved re-settlement of 80,000 people in* ***Pawe*** *region of Gojjam with supporting irrigation and infrastructure works such as airport, schools, factories, hospitals, etc. It was later abandoned and should not be confused with the new* ***Tana-Beles Multi-Purpose*** *project which also involves building a 460 Mega Watt hydroelectric station along with two tunnels and irrigation of the* ***Beles*** *basin.*

Organization and Technical Details of the Project

While Studio Ing. G. Pietrangeli S.r.l. of Rome, Italy provided the engineering design and consultancy components, Salini Costruttori, S.p.a. was involved in coordinating financing as well as contractor-ship for the project as a senior partner in this professional association [3]. For the most important component - the 26kilometer tunnel - the consultancy services of another Rome, Italy based company, S.E.L.I. S.p.a was acquired as a sub-contractor [4]. S.E.L.I. S.p.a. is also a reputable company with experience in projects in various parts of the world. This association between Salini Construttori, Studio Ing. G. Pietrangeli, and (wherever needed) S.E.L.I. is also a trademark of the new 460 Mega Watts **Tana-Beles** hydroelectric project (scheduled for commissioning in March/April 2010), the Gibe III and Gibe IV projects. From the Ethiopian side, the country's energy authority EEPCo (Ethiopian Electric Power Company) represents the government as well as the interest of the Ethiopian people as a client.

The Gibe II project was originally estimated to cost €375 million. The financing for the project comes from the government of Italy that supplied €220 million as a soft loan, European Investment Bank that covered €50 million as a loan and the Ethiopian government that put €105 million. Supporting infrastructure such as roads and high-voltage transmission lines as well as project management and consultancy fees were estimated to cost another €100 million bringing the total estimated cost of the project to €475 million ($665 million) [5]. The project has various engineering components such as: (i) inlet structures on the Gilgel Gibe River side (diversion canal, coffer dams & storage weir), (ii) outlet structures on the Omo River side (penstocks, four 105 Mega Watts rated Pelton type turbines, and high-voltage switch yard), and (iii) 26kms long tunnel with internal diameter of 6.3meters. As shown later, the tunnel's diameter was eventually changed to 6.93m as one of the responses to the several problems the tunneling operation encountered. The excavation of the tunnel was carried out by two massive 255 ton tunneling digging machines called TBM (Tunnel Boring Machine) that operated from both sides of the tunnel.

II. DESCRIPTION OF THE TECHNICAL PROBLEM

In this section, we outline the technical problems with the tunnel reported so far and assess if it is indeed an engineering design error or error related to wrong assumptions of geology and topography. Then, we will closely look at failures of previous large-scale infrastructure projects in Ethiopia to identify what sort of systemic flaws existed and contributed to the failure of the projects. A detailed review of the seismicity of the area around the project is included to make a determination of risks posed by seismic hazard.

1. Continued Problem with Tunnel Culminating with Recent Failure

To understand the nature and extent of the series of problems with the tunnel, one has to look at the engineering drawings of the cross-section of the geology of the site published publicly by S.E.L.I. S.p.a Tunnel engineers themselves [6,7]. As shown in Figure 4, the tunnel has a diameter of 6.98meters and extends for 26 kilometers and is designed to withstand a maximum pressure of 7 Bar (1 Bar ~= the normal pressure at sea level). The tunnel is buried deep in the ridge formed by **Fofa** Mountain at depths varying from 300meters to almost a kilometer at its deepest section.

The ridge through which the tunnel is dug is made up of a non-uniform rock formation with several types of rocks with the dominant ones being basalt on the west side followed by trachite and rhyolite on the east side of the tunnel [6,7]. As the figure shows, the ridge is intersected by numerous faults generally inclined in the east direction.

The first failure during the construction of the tunnel happened in **October 2006** when the tunneling crew hit a pocket of wet earth along a major fault line only 4 kilometers into the boring [6]. Wet and humid mud under a pressure of as much as 40 Bars and with temperatures reaching 40^{o}C gushed out [6]. This immense pressure which is almost <u>6 times the maximum pressure of 7 Bars that the tunnel was designed for</u> not only damaged the tunnel itself and its linings but also the 255 ton tunnel digging machine. A summary of the failures as reported by the tunneling engineering consultant read as follows: **'***Event at the chainage 4+196 from intake heading. At the end of October 2006, the TBM was pushed back as consequence of the sudden extrusion and collapse of the tunnel face against the cutter head and the front shield.* ***The tunnel face moved towards the TBM 40-60 mm/hour.*** *The TBM has been pushed back more than 60 cm and displaced laterally more than 40 cm. As consequence, severe damages occurred to the shields, the cylinders and the last 7 segment rings installed behind the TBM*.' [6]

A second failure also occurred in June 2007 resulting in the collapse of the front face of an exploratory tunnel which eventually filled 80meters of the main tunnel with mud [6]. Further, in August 2007, unexpected fault line was crossed during excavation; but with no reported damage at that time. The solution to these series of unforeseen events involved (i) building a new 230meters of bypass tunnel, (ii) changing the original layout (direction) of the tunnel, (iii) dredging as much as **40,000** cubic meter of mud continuously for 2 years (between October 2006 – August 2008), and (iv) filling out the failed section of the tunnel with concrete. These remedial measures, we believe, constituted significant departure from the original design.

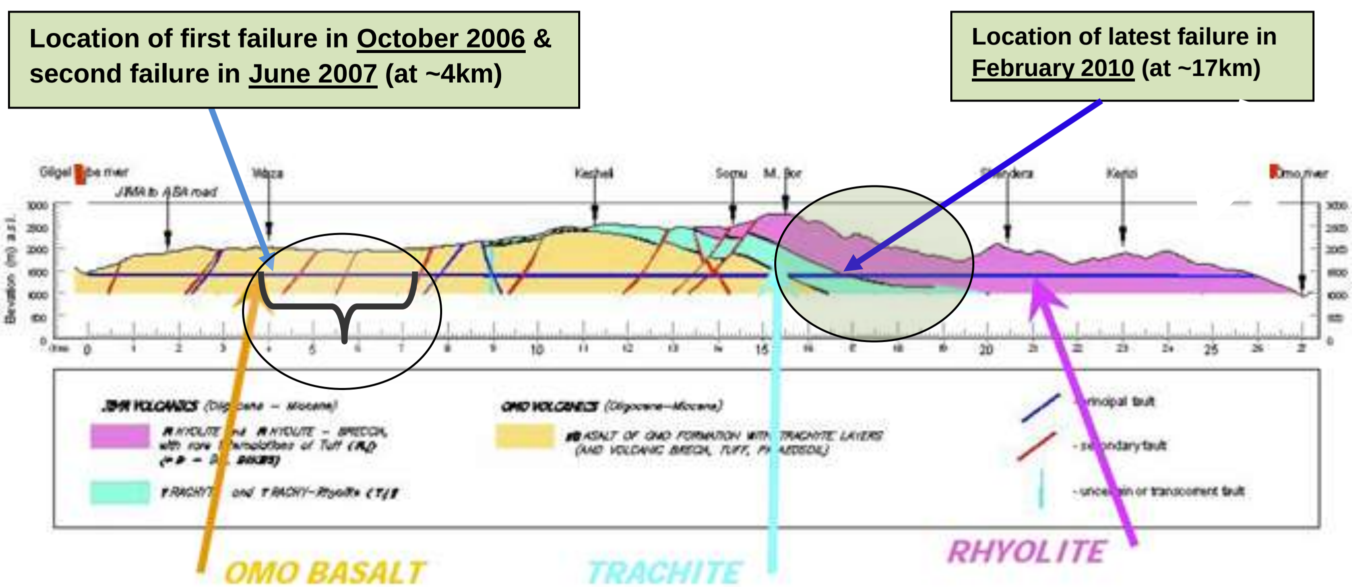

Figure 4. Cross-section of the tunnel showing multitudes of fault lines [6,7]. Later failures showed that there were still more fault lines unforeseen at the beginning of the project. Image taken S.E.L.I.'s public report from [6,7].

The latest failure occurred in February 2010, three and half-years after the first series of failures. In the words of the tunneling consultant engineer, "the cause was *extremely high rock/mud pressure of a major fault associated with loose cyclopic dolerite blocks and round boulders. One possibility is that the faulty ground (high pressure mud mix with round boulders) in this area was separated from the tunnel by a relatively thin diaphragm of a fractured dolerite dike. When mud pressure was able to break the diaphragm, a sudden concentrated and dynamic load of mud and blocks acted on the tunnel section causing the damage*." [7]

Figure 5. Image of the damaged section of Gibe II tunnel that failed in October 2006 under pressures that exceeded the design pressure by six times [6].

As it turns out, this is the second time that mud under high pressure had broken into the tunnel area. A report on an industry forum called 'TunnelTalk' quoting S.E.L.I. S.p.a. has suggested that the event occurred on a new location about 9kms from the outlet with affected length of almost 15m. It was also stressed that a large quantity of rock and mud fall into the tunnel [8].

Based on the above statements from the consulting company itself, we believe there is good-enough evidence to suggest that all the failures reported so far on the tunnel were caused by geological and possibly geophysical events which were not accounted for by the tunneling engineering plan. Again, based on our review of the published material on the subject, we did not see any evidence of third-party independent review of the failures as well as the remedial measures by external experts. The obvious question at this juncture is what the probability and possibility of future failures in the tunnel are. We will offer our professional opinion in subsequent sections.

2. **Failures of Previous Large-Scale Infrastructure Projects**

In our effort to assess if such structural failures as seen in the Gibe II project arise from systemic flaws or not, we investigate past large-scale projects that could shed light on this. We believe the case of the original **Tana-Beles Agro-Industrial Project** is very much relevant here. Started in 1988 through the personal involvement of the then political leader, Colonel Mengistu himself, Tana-Beles Agro-Industrial Project was a €150 million project. The financing was provided by the Italian government and both Studio G. Pietrangeli and Salini Costruttori were involved in its design and construction. This well-meaning massive project consisted of 250,000 hectares of agricultural land for 80,000 resettled farmers spread over brand new 50 villages. The supporting infrastructure included extensive road networks, water distribution, and airport. A modern hospital with general practice, surgery, pediatrics, radiology, obstetrics and gynecology departments was also included. In addition, a rice-processing factory, a pipe factory, a plastic factory, guest houses, office buildings, housing for workers, and a meeting hall were planned as part of this €150 million project.

Figure 6. Studio Ing. G. Pietrangeli was involved in the design work for the original **Tana Beles Agro-Industrial Project** that was partially financed by Italy.

A victim of the changing political atmosphere in the country and the politicization of the project due to the deep personal involvement of then political leaders, the project faced innumerable difficulties culminating in the withdrawal of Salini engineers from the country. Subsequently, the project turned into a desolate area and remained mostly so until 1997 where it was a scene of abandoned factories, warehouses, administrative buildings, guest houses, roads and bridges [9]. In the late 90s, only 30,000 out of 80,000 re-settled people remained in the area. Others reportedly died of malaria, famine, diarrhea; some managed to escape [9]. Currently, there is some rehabilitation of the project in somewhat distinctly different form as the Tana-Beles Multi-Purpose project.

Figure 7. A closed and desolate rice-processing factory in the original **Tana-Beles** project [9]. The other three pictures show foundation Failure of three buildings at the **Akaki** Spare Parts Factory [10].

The reason for the failure of the original project is the fact that the top political leader of the time acted as the chief-planner, chief-economist, chief-engineer, and chief-medical-officer in charge of everything without a proper delegation of responsibility to trained professionals. Further, there was no over-sight and check-and-balance system of any sort from the Ethiopian side that could have limited its extremely ambitious scopes to manageable tasks. At the end, the product is a failed project that cost hundreds of millions of dollars but with negligible use for the Ethiopian people.

The second example is that of the **Akaki** Spare Parts factory that was built in the late 1980s by the Italian government with no input at all from their counter-part Ethiopian side. Again, we believe, the intent was noble but the most visible negative outcome of the project was the fact that it was built on a black cotton soil that expands with moisture presence and then shrinks during the dry season. The absence of simple engineering 'sanity-check' by independent review system from the Ethiopian side resulted in the structure functionally damaged with foundation failures that translated to multitudes of structural cracks in the walls, floors, roof, windows, doors, etc [10]. The structure continues to be a dangerous structure; but due to lack of will and huge expenses to remedy the blunder, it is still in use.

We believe that these two examples demonstrate extreme cases where the systemic flaws of lack of oversight and check-and-balance system, particularly when the contractors is also the source of funds eventually end up in causing colossal damages to the interest of the country and its people.

There are a few lessons we have to learn from these failed projects which were both financed by a foreign government (Italy, in both cases).

1) There is no over-sight when the financer is a foreign government even though the financial burden of operation and living with the consequences fall on the recipient country.
2) In both cases, there was no reported consultancy with local engineering professionals who have intimate knowledge of the country's unique needs and conditions.
3) As a result, both were catastrophic failures.

3. Seismicity Concern in the Project Location

A crucial aspect of any project – particularly large-scale infrastructure work – planned in the well-known seismically active regions of the country such as the Afar Triangle, the Main Ethiopian Rift, southern Rift Valley and the surrounding areas is the determination of seismic risk in the life-span of the project and subsequently designing accordingly following the established practices of seismic-resistant deign.

Therefore, when evaluating any potential failure risks, key question regarding this seismic hazard and its mitigations arise. We pose the following questions:

1) Is the area covered by Gibe II (and for that matter Gilgel Gibe I, Gibe II and IV) susceptible to seismic hazard?
2) Is seismic hazard a contributing factor in the failure of Gibe II tunnel? Will it pose a serious risk in the future?
3) Does seismic hazard pose risks to the other projects, particularly GG III and GG IV?

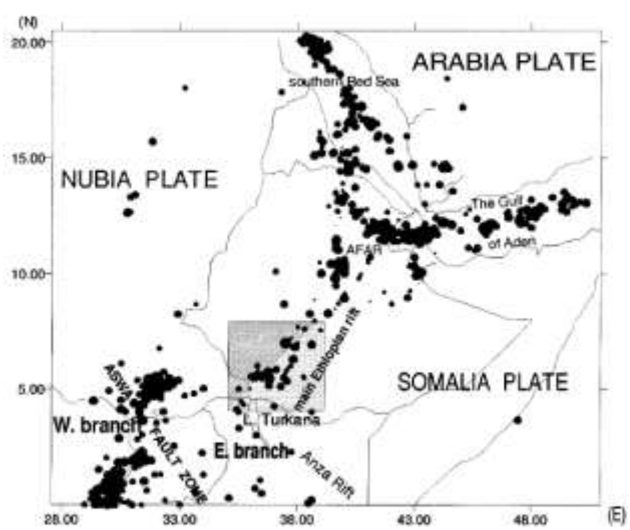

Figure 8. Seismicity of Ethiopia, with particular emphasis on the Main Ethiopian Rift as well as the southern Rift Valley (Atalay Ayele 1995) [19,20]. The dots represent earthquake locations.

We answer these questions in this section. In a series of articles, Ethiopia's eminent seismologist Dr. Laike Mariam Asfaw[5] of the **Geophysical Laboratory** at Addis Ababa University (now **Institute of Geophysics, Space Science, and Astronomy**) has reported on the seismic nature of the location that lies between 4^oN and 7^oN Latitude and 36^oE and 38^oW longitude. This area which stretches from Moyale to Sodo (South-North) and the Kaffa region to Moyale (West to East) contains the larger Gilgel Gibe/Gibe/Omo Valley area where Gibe II as well as GG III and GG IV projects are located.

For example, Table 1 taken from a work reported by Dr. Laike Mariam Asfaw in 1990 summarizes the thirteen large earthquakes that have hit the area between 4^oN and 7^oN and 36^oE and 38^oE since instrumentation began [11]. Notable is the 6.2 magnitude quake that hit the region on October 25, 1987. Further, Table 2 summarizes so-far unpublished reports recorded on damages and panic caused by the earthquake swarm of 1987 with epicenters located within the same area. The table shows that even at distances of 100-250kms away from the epicenters of the seismic events, damages to structures as well as landslides were reported in the cities of Arba Minch and Jimma. The work of the up and coming seismologist Ayele Atalay and his colleague [12] also supports these findings where the 07/10/1987 event caused building damage. The 25/10/87 event, according to A. Ayele also caused considerable damage and landslides over a wide area.

Figure 8 summarizes the seismicity of Ethiopia, with particular emphasis on the Main Ethiopian Rift (MER) as well as the southern Rift Valley [18]. The specific seismic events in the area near the project locations are highlighted in the figure. Additionally, Figure 9 shows the location and distributions of major seismic events in this area of interest along with known prominent fault lines [13]. Figure 10 shows the **e**picentral distribution of well located earthquakes from 1985 to 1987 in MER (Main Ethiopian Rift) as reported by L.M. Asfaw [11,14-16]. One of the most important evidences is the photo that shows one of the many samples of surface fractures taken by L. M. Asfaw at a field observation after the December 29, 1987 earthquake swarm. This surface fracture has a significant engineering implication emphasizing the kind of failures that could have negative consequence on structures like tunnels.

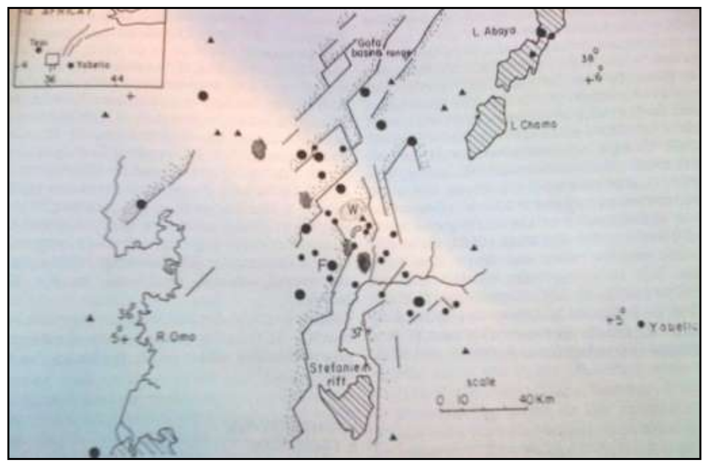

Figure 9. Seismicity in Gammo Gofa, Kaffa, and Jimma regions [11,13,14].

As well known in the seismologist's community, the geology and tectonics of the area south of the Main Ethiopian Rift (MER) between 4^oN and 6^oN was relatively not well-understood until the publications of Dr. Laike Mariam Asfaw came in 1990 [11]. L.M. Asfaw's work outlined the main features in this region as the two symmetrical rifts containing **Lakes Abaya** and **Chamo** in the north and **Lake Stefanie (Chew Bahir)** in the south. West of the Abaya – Chamo rift is the **Gofa Basin and Range Province**. This geologically prominent region is intersected by numerous fault lines and is less than 100 kms from the Omo/Gibe valley. The Turkana Rift with its two northern branches containing the Omo Valley and Unso River Valleys is located to the west of the Stefanie Rift.

Additional body of research on the seismicity of this area was reported by A. Ayele and R. Arvindsson [12] who re-assessed the seismotectonics of the southern part of MER (Main Ethiopian Rift) from recently available earthquake data. They argued that the southern extreme of MER is characterized by highly dissected rugged terrain and multiple rifts that is dominated by NNE trending multiple rifts distributed in the NW-SE direction (that L.M. Asfaw calls '**Tepi-Yabello'** axis shown in Figure 1). They also point out that there is '*extensive stress regime'* both in MER and the so-called Gregory Rift that stretches from the lower Omo Valley to Kenya.

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[5] *We feel it is important to mention* ***that Professor Laike Mariam Asfaw*** *is an internationally known seismologist whose opinion and expertise is widely sought by top experts around the world. His most important contributions include maintaining a world-class research in seismology of the country during the difficult years of 70s and 80s and training a new generation of top seismologists [21].*

With engineering implications of these seismic activities in mind, we set out to further analyze the earthquake data of L.M. Asfaw as shown in Figure 11. As the figure shows, the time elapsed between major events in this area varies from a minimum of 2 years to a maximum of 17 years. A similar analysis of the time elapsed between successive earthquake felt in Addis Ababa (with intensity > 5.0) presented by L.M. Asfaw [16] is shown in Figure 12. While this study has to be supplemented by a study of the stress build-up in the earth crust in these areas using what seismologist call '*b-value'*, the periodicity at which the stress has been released so far as a seismic event may give an indication of the next expected seismic event. However, the earthquake data set in this area is not complete enough to be amenable for determining the '*b-value'* as A. Ayele and his colleague had pointed out [12]. Nonetheless, based on the above discussions and the fact that this current time frame represents the longest stretch with no noticeable seismic events, we believe that there is credible ground to suspect that the area under consideration here (i.e., between 4^{o}N and 7^{o}N and 36^{o}E and 38^{o}E) may be overdue for a seismic event of 5.0 or higher intensity [16].

Date	Latitude (N)	Longitude (E)	Magnitude
September 16, 1913	4.3	36.7	**6.2**
October 4, 1928	6.9	36.9	**6.0**
November 30, 1937	5.1	36.9	**6.3**
June 30, 1954	5.8	37.2	5.9
February 4, 1955	5.8	36.8	5.3
October 24, 1965	5.6	37.2	5.1
May 8, 1967	4.3	35.7	5.0
January 7, 1973	5.6	36.9	5.7
August 20, 1985	5.5	36.1	5.4
October 7, 1987	6.2	37.8	5.3
October 25, 1987	5.4	36.8	**6.2**
October 25, 1987	5.1	37.2	5.8
October 28, 1987	5.7	36.7	5.6

Table 1. Major seismic events in the area under consideration (after L.M. Asfaw [11]).

Event	Report from Site	Coordinates and Distance of Reporting Site from Epicenter
October 7, 1987 Past mid-night local time Intensity = 5.3	**Arba Minch** Rock slide, many buildings cracked, general panic.	**6^{o}.02 N, 37.57 ^{o} E** 113 kms
October 25, 1987 Evening local time (16:46:13.3) Intensity = 6.2	**Jimma** Wide-spread panic, inhabitants fled their home. Wall moved strongly, felt in Dodola 339 km. away	**7^{o}.68 N, 36.83 ^{o} E** 252 kms
October 28, 1987 Morning local time (08:58:29.1) Intensity = 5.6	**Arba Minch** Already weakened blocket building collapsed. Strongly felt in the city	**6^{o}.02 N, 37.57 ^{o} E** 98 kms
Ditto	Jimma Panic. No damage.	**7^{o}.68 N, 36.83 ^{o} E** 216 kms
Ditto	Sawla Poorly built house collapsed	**6^{o}.30 N, 36.88 ^{o} E** 64 kms

Table 2. Summary of damages due to the seismic events in the area under consideration (after L.M. Asfaw, 1990 [11] and unpublished report in Amharic [15]).

Against this background, Section 2.3.1.1 of the 'Executive Summary: Environmental & Social Impact Assessment for GG III' says *'While the Gibe III dam is located in Ethiopia, in the vicinity (about 70 km) of the eastern branch of the east African rift system the entire area interested by the project, according to Level 1 Design Geological Report, doesn't show any evidences (sic) of present existing (sic) seismic activity.*' This report was authored by CESI (Italy), MDI Consulting Engineers (Ethiopia), ESIA, and Agriconsulting (Italy) which were all consultant to this project hired by EEPCo and Salini [18].

Given the fact that there is sizable amount of reports and published materials on the relatively high seismic hazard of the area covered by the project – as established in detail above – this key and fatal statement from the mainly Italian consultants brought by Salini Costruttori S.p.a. comes across not only as erroneous but also reckless. In fact, we believe that an increasing amount of evidence is building with the indication that the majority of the problems with the Gibe II project may stem from this incorrect assumption that may have never been independently reviewed. As engineers investigating the reason behind the tunnel problems of Gibe II, we could not have come across any other devastatingly powerful evidence that matches this in terms of the utter disappointment in the engineering process that was followed. Further, the absence of a mechanism for one more level of check-and-balance system where the client (EEPCo) could have sought the counsel of seismologist and geophysicists at **Amst Kilo** who had extensively studied and published on the seismic risks of this particular area where earthquakes of as much as 6.2 magnitude were recorded is of considerable concern.

Therefore, in light of this background information, we are very much puzzled how such an erroneous conclusion stayed unchallenged in the Executive Summary of Gibe II and Gibe III projects – infrastructures worth more than $ 1billion! In fact, even if we had set out at the beginning to address the case of Gibe II only, the Executive Summary was written for the larger and more expensive Gibe III project and we are duty-bound to raise a very critical question on the soundness of any engineering decisions made for subsequent projects based on this erroneous assumption.

Our professional opinion is that any of the Gibe projects should consider seismicity into the design and construction processes. Neglecting the risks posed by seismic hazards in such a region with recorded history of significant seismic events, we believe, has tremendous negative consequences in the future usefulness of these projects. Again, the evidences suggest – particularly the damaging report in the 'Executive Summary' – that seismic risks were not considered in the engineering design of the tunnel. In fact, the failures reported always occurred near faults – even when no seismic event occurred further highlighting the dangers these projects face in actual seismic events.

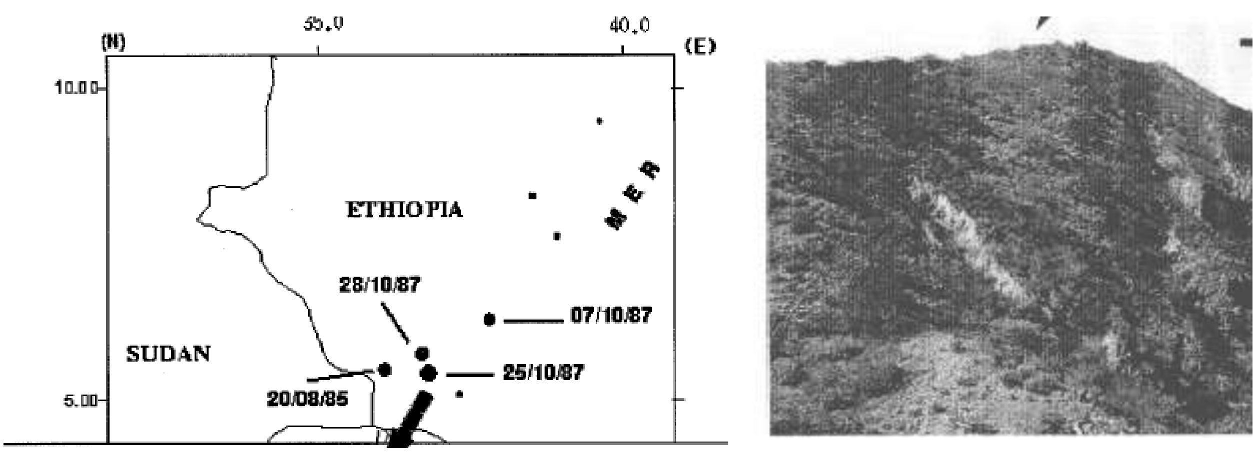

Figure 10. Epicentral distribution of well located earthquakes from 1985 to 1987 in MER is shown in the inset [12]. The attached photo is one of the many samples of surface fractures taken by L. M. Asfaw at a field observation after the 29 December 1987 earthquake swarm. This swam occurred about the epicentral area of the main shock, around the tail of the black arrow [11].

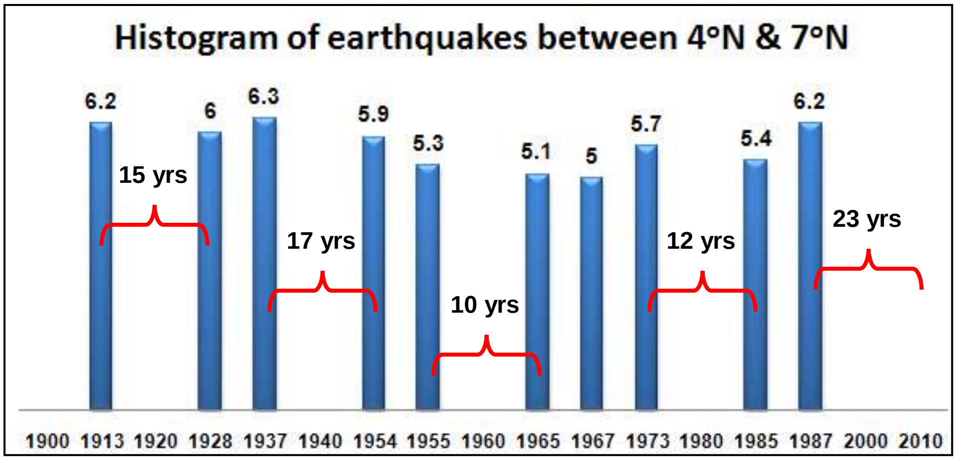

Figure 11. Histogram of major seismic events in the area under consideration [11,14-16] with time elapsed between major earthquake events [17].

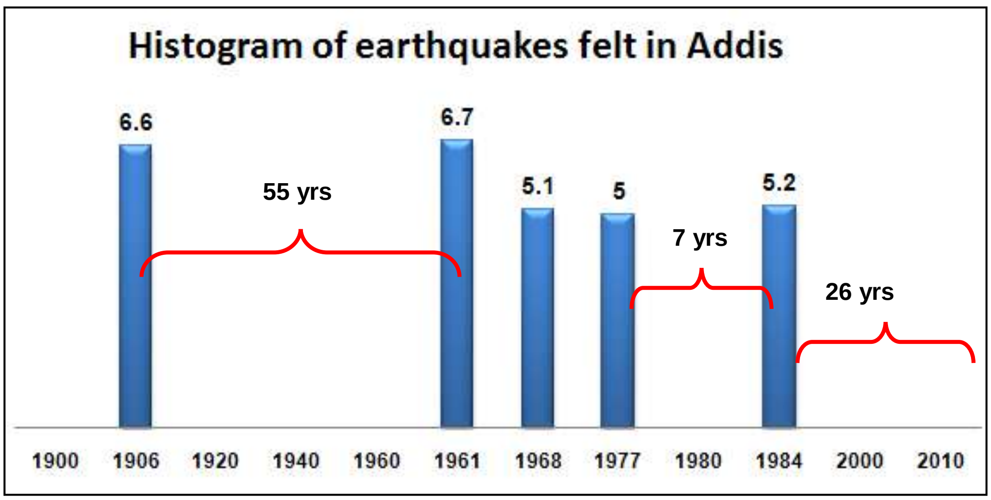

Figure 12. Histogram of major seismic events felt in Addis Ababa as reported by LM. Asfaw [16] with time elapsed between major earthquake events [17]. It must be noted that there is no indication if the seismic events reported in [16] were given in M_L (local earthquake magnitude) or as M_S (surface wave magnitudes). Therefore, to avoid inconsistence in comparison, we have not included the 5.2 M_L earthquake of September 2009 that was felt in Addis Ababa.

4. <u>Lack of oversight and check-and-balance mechanism</u>

With the evidences presented above, we then look at the specific reasons why such problems were not detected before and dig into the systemic flaws that played a crucial role. We believe answers to the following questions are pertinent to help identify the systemic flaws.

1) Was the engineering design of Gibe II project (particularly the 26 kilometer tunnel in such a difficult terrain) ever reviewed by independent body with no conflicts-of-interest?
2) When the first and subsequent failures in the tunnel occurred, did the client represent the Ethiopian people ethically and asked for independent review of the problems?
3) Why weren't Ethiopian seismologist consulted given that the Geophysical Laboratory has a very much respected track record?
4) Were Ethiopian geotechnical and structural engineering professionals both inside the country as well as in the Diaspora consulted to offer independent review?

5) What are the systems the client (EEPCo) has put in place to assess constructional problems as well as liabilities due to negligence?
6) What are the mechanisms in place to address future failures of any component of the project?

To answer these questions, we look at key examples around the world that are relevant to the case of Ethiopia.

4.1 Examples of Standards of Transparency

(i) The case of World Bank

The World Bank, for example, sets a rigorous '*Standards of Transparency'* and a meticulous selection procedure to qualify consultants participating on the study of projects of comparable significance to the Gibe II project. As a rule, the overriding reason for such a full-proof process is to preclude any form of corruption from tainting the process and hence jeopardizing the funds as well as to assure that projects are executed "right".
As is outlined in World Bank's Consulting Services Manual 2006[6], the Bank's policy on the selection of consultants is guided by the principles of:

a. High quality of services,
b. Efficiency and economy,
c. Competition among qualified consultants from all eligible countries,
d. Participation of national consultants (i.e. Local consultants) and,
e. Transparency.

It is clear that items '*c*' and '*e*' are very much relevant to the case of Gibe II project.

(ii) The case of Transportation Infrastructure – State of California

In the case of state-level oversight of major infrastructure projects, the example of state of California is instructive here. The California Department of Transportation (Caltrans) sets '*Quality Control'* goals for an external consultant to adhere to when designing bridges or tunnel structures. This is clearly outlined in the Office of Specially Funded Projects (OSFP) Procedures Manual[7] which states that '*structure design calculations and independent design check calculations must be submitted as part of the Plans, Specifications & Estimate (PS&E) submittals*.'

Caltrans stipulates that quality control for the design integrity and the completeness of project documents are the responsibility of the consultant. The consultant is expected to have a quality control plan in effect during all project phases. Further, it is stipulated that plans, specifications, calculations, reports, and other items or documents delivered to OSFP for review shall be clearly addressed in the quality control plan established for the work. Caltrans further requires that the 'Quality Control Plan' should contain well-defined appropriate checklists to assure product quality and control.

(iii) The case of San Francisco–Oakland Bay Project

We look at a particularly large infrastructure work in state of California that involves building the massive San Francisco-Oakland Bay Bridge Project (SFOBBP). When T. Y. Lin International – a well-known civil engineering company - undertook the design of this bridge, as an external consultant, California Department of Transportation regulations required them to submit the resumes of all their engineers as well as sub-consultants. Individual resumes were then reviewed and approved by Caltrans before any of the consultants could start work on the design of SFOBBP. Subsequently, a "Design Check" office was setup within T.Y. Lin and the list of Consulting Engineers was presented to Caltrans for their review and approval. The major requirement for the "Design Check" team was that there had to be a clear demarcation line with the Design Group. None of the engineers who worked on the Design of the SFOBBP was allowed to work on the "Design Check" team. This policy has been ingrained in all Caltrans Bridge/Tunnel Designs to assure a fresh "set of eyes" looks at the design approach and preclude duplicating any errors that may have been made by the Design Engineer. At the onset of the "Type Selection" of the Bridge- as is always the case - various alternative designs are presented along with their

[6] *World Bank Consulting Services Manual 2006, Selection of Consultants,*
[7] *California Department of Transportation, Office of Specially Funded Projects (OSFP) Procedures Manual,*

attributes and shortcomings. These alternatives are carefully evaluated on a point system and value analyzed before the final decision following the Agency's 'Value Analysis flow Chart'.

The lesson here is the importance that is attached to third-party independent review of engineering design to large-scale projects around the world.

4.2 Procedure Followed in Gibe II Project

From the background information pointed out in various published papers, it is widely reported that:

a. Salini Costruttori undertook this project as a turnkey project thus bypassing the crucial step of the consultant selection process.
b. Not only Salini Costruttori bypassed this important step, but it also bypassed the plan-check process by the Client (EEPCo).
c. There was no feasibility study for Gibe II project and that there was no open competitive tender that took place to award this project to Salini Costruttori.

We submit that – as practiced elsewhere in the world and well known in the industry- the three guiding tenets of construction in the order of priority are quality, cost and time. The quality of the project takes the highest priority followed by cost of construction and finally timely completion of the project. Therefore, when an owner awards a contract without an open tender to an experienced contractor like Salini Costruttori, it would only put itself at a price disadvantage; meaning it would lose money by not getting the most competitive bid price. However, it needs to be remembered that because of the level of expertise of a contractor like Salini Costruttori, the Quality of work is not usually compromised if the Contract Management/Inspection is conducted by a knowledgeable representative of the owner (EEPCo, in this case). Therefore, we believe, the most critical error in the award of the Gibe II project was not that of awarding the project to Salini Costruttori as such but the sweeping authority granted to Salini Costruttori to bypass any third-party and independent oversight.

Again, as well know in the industry, the two important steps that should never be bypassed in the study of major infrastructure projects are (i) <u>transparent consultant selection process</u> and, (ii) <u>independent oversight</u> of the selected Consultant himself by the Owner (or his Technical Representative). As discussed above, the prime engineering design consultant Salini Costruttori handpicked to undertake the design of Gibe II was Studio Pietrangeli S.r.l. The function of the Prime Consultant in a typical setup would be to undertake the overall study/design of the project. Because this project is primarily a tunnel project with no significant dam structure per se, the tunnel work was subcontracted to S.E.L.I S.p.a., a worldwide Tunnel Boring Machine (TBM) Manufacturer and Tunnel Builder. Because there was no feasibility study done and because there was arguably no thorough geophysical study done, the knowledge of what the subsurface challenges are, are simply left for S.E.L.I S.p.a. and its internal consultants or sub-consultants to figure out. There was simply no oversight on behalf of EEPCo, Ministry of Mines or Ministry of Water Resources from the Ethiopian Government side to challenge the major milestone decisions made in the design of the Tunnel, especially in relation to the geological and geophysical study.

As a clear example of violation of the need for independent review and oversight, we mention the case of the repeated tunnel failure due to pressurized earth near fault lines. As reported in TunnelTalk, *"…The second TBM, driving from the outlet portal, fared better despite passing through several fault zones and experiencing hot water inflows of up to 54°C (129°F)'* [8]. It is very alarming that this did not trigger a distress signal for S.E.L.I S.p.a. and the tunnel consulting engineers to approach the construction failure as a geologic and possibly as a seismic stability issue and that this may mean a possible existence of seismic activity in the area. And if so, this should have substantially changed the design of the tunnel, to allow flexibility in the design and construction of the tunnel with even a "double-barreled shield tunnel" design approach among others.

To make matters worse, the current "fix" of the tunnel collapse is completely left in the hands of Salini Costruttori, S.E.L.I and their consultants. As the evidences suggest, no independent consultant is involved even at this stage and the Client/Owner is simply waiting for a "quick fix" to happen so that it would resume its power generation in short order. But is this "quick fix" really a long term "fix"? We believe this is a question of immense consequences.

III. Suggested Solution from Engineering & Contract Administration and Project Management Point-of-View

In this report, we have investigated why the Gibe II project faced a number of failures in its most important component, namely the 26kms tunnel. We believe that consequential flaws in the very process of conception-to-completion aspects of large-scale infrastructure projects of the country as well as the engineering itself carried out by this particular project's design consultant are the main causes.

We recommend the following to help fix the systemic problems that have led to constant failures as well as what we believe is unacceptable level of risk of failure in the future. We believe that these recommendation go very well hand-in-hand with capacity building and better business practice initiatives that are being aggressively pursued in the country now.

A) Recommended Engineering and Design Specific Fixes

1. Form a Technical Inquiry Committee immediately to evaluate the validity of the "fix" presented by the contractor and its tunnel sub-consultant.
2. The Inquiry Committee shall have the following members as a minimum:
    a. Seismologists and geophysicists from the Institute of the Geophysics, Space Science and Astronomy at the Addis Ababa University,
    b. Geologists from Ministry of Mines who are thoroughly familiar with the geologic formation of the Gibe/Omo basin,
    c. Structural, geotechnical, and hydraulic engineers from Engineering Departments of AAU and Universities abroad and,
    d. Representatives from professional engineering associations, i.e., EACE (Ethiopian Association of Civil Engineers), ESME (Ethiopian Society of Mechanical Engineers), and Society of Ethiopian Electrical Engineers (SEEE),
    e. Engineering Consultant with a broad ranging experience working in seismically active areas anywhere in the world with an extensive foundation construction/design experience,
3. This Committee may be chaired by a practicing engineer with wide range of both design and construction experience with no link/affiliation with any of the Gibe II design or contracting firms,
4. The Chair of this committee shall report directly to EEPCo or the governing body overlooking this tunnel failure,
5. The "fix", as outlined above, shall include seismic considerations with a broad range of solutions on how to accommodate for the fault movement along the tunnel axis.
6. Install seismic ground motion measuring instrument in and around the tunnel area as a mandatory component of the "fix".
7. For minor damages due to ground movement, install rock trapping mechanism at the tail end of the tunnel to protect the 4 Kaplan turbines.

B) Recommended Process Related Fixes

1. Review the contract awarding mechanism for large-scale infrastructure projects to include independent third-party review system for all important components such as engineering, environmental impact, construction administration, etc.
2. As part of the third-party review process, include Ethiopian professional organizations and experts with more intimate knowledge of Ethiopia's needs and challenges.
3. Introduce transparency to the execution of projects by requiring both foreign and domestic contractors and engineering consultants to present technical reports on progress and challenges in each of the projects that they undertake to annual conferences of professional organizations such as EACE, ESME, and SEEE.

In addition, we believe, that one of the most important lessons that has come out of this engineering report is how seismic hazard considerations will be a very significant part of any large-scale infrastructure projects in south Ethiopia. Given this, we recommend that adequate seismic monitoring capability be provided for this region by building geophysics labs at **Arba Minch** and **Jimma** universities through the mentorship of AAU's Institute of the Geophysics, Space Science and Astronomy.

IV. CONCLUSIONS

In this rather exhaustive engineering report, we have investigated why the Gibe II project faced a number of failures in its most important component, namely the 26kms tunnel. We have outline the technical problems with the tunnel reported so far and – with the supporting evidences - showed that that it is indeed an engineering design error due to wrong assumptions of geology and topography. We have also closely looked at failures of previous large-scale infrastructure projects in Ethiopia and outlined that systemic flaws existed and contributed to the failure of these projects. Perhaps, more importantly, we have carried out a detailed review of the seismicity of the area around the project based on published results.

The review showed that the region around the project area has a recorded history of significant seismic events. The outcome of our study shows that projects such as GG II, GG III, and GG IV should consider seismicity into the design and construction processes. Neglecting the risks posed by seismic hazards in such a region with, we believe, has tremendous negative consequences in the future usefulness of these projects. Again, the evidences suggest – particularly if the damaging report in the 'Executive Summary' is what was used as guidance– that seismic risk was not considered in the engineering design of not only the Gibe II tunnel but also for all major structures of the more expensive 1.4GW GG III and the planned GG IV projects. But the facts prove as shown in this report that the failures reported in GG II always occurred near faults – even when no seismic event occurred further highlighting the dangers these projects face in actual seismic events.

This engineering report has also outlined a detailed review of the contract award and administration aspect of the project and determined that there is a systemic flaw highlighted by the total absence of over-sight and independent third-party review of engineering design when the financer is a foreign government.

Once the problems were identified, we have outlined suggested remedial measures for this project of immense national importance. The remedial measures suggested constitute what we believe are basis for a sound engineering practice when it comes to large-scale projects in the country.

We want to emphasize that, as things stand – with no independent review - there is no credible way of assuring that the fixes being considered for the series of failures of the tunnel in Gibe II project could hold fine for a reasonably long time. If we are lucky, the seismic and geological events in the area could be minimal in for 10-20 years or so. However, living the fate of such an important and expensive project to rolling a dice is not a sound practice.

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