APETT’s Mission:
The Association of Professional Engineers of Trinidad and Tobago is a learned society of professional engineers dedicated to the development of engineers and the engineering profession. The association promotes the highest standards of professional practice and stimulates awareness of technology and the role of the engineer in society.
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Editor’s Message
Eng. Julio Bissessar

It is with great privilege that I write this message as the newly elected Magazine Editor of APETT. I would firstly like to thank Eng. Imtiaz Easahak (President Elect) and Eng. Anna Warner (Chemical Division Chair) for granting me this amazing opportunity. I could not be more delighted.

This magazine edition is the first of its kind for APETT in that it reflects the great work that has been produced by engineers of Trinidad and Tobago from Chemical/Process, Mechanical, Electrical and Civil Engineering. It shows the true nature of us as a local community and the sheer vibrance that keeps us going to assist in the betterment of the engineering industry both on a local scale as well as globally.

As always in engineering, we stress on safety; I am delighted to share Eng. Rae-Ann Joseph’s article on the Bowtie Methodology with respect to Process Safety Engineering and why it is of utmost importance to industry. Also, many thanks to Eng. Aaron Gayah on the analysis of Process Safety Valve (PSV) maintenance and sparing strategies. Eng. Dexter Daniel gave his expert analysis on the improvement of access scaffolding in Trinidad and Tobago’s industry, leading to reviewing standards and codes.

Innovation and creativity is always encouraged in engineering, especially when the end result is ensuring that future generations exist to benefit from its development. Eng. Matthew Kubanali ventured to discuss the implications of utilizing renewable energy initiatives to essentially tie into the grid system making it both beneficial to humans as well as the surrounding environment. Eng. Brendon Inniss also shared his wealth of knowledge surrounding the use of Welded Wire Reinforcements for Reinforced Concrete building construction.

A special thanks to Eng. Dr. Aufderheide, Eng. Makeda Wilkes and Eng. Adrian Lutchman for their work linking Biomedical engineering with Chemical Engineering and Controls. Eng. Ancile Brewster gave a thorough analysis of diversifying the economy from oil and gas in a perspective of investing in maritime infrastructure and logistics. We are all aware of the state of the economy, so it is great to hear an engineer’s perspective on diversification.

I, myself, have also written an article utilizing Partial Differential Equations (PDEs) to essentially “construct” a mathematical model of a glass forerearth system, one that is used in the manufacturing sector, in particular the manufacture of glass bottles.

Lastly, I would like to thank all persons who contributed articles towards this magazine; it was greatly appreciated and it would definitely benefit the wider Science, Technology, Engineering and Mathematics (STEM) society both locally, regionally and internationally. I would like to give a special thanks to Eng. Krisshala Sinanan (Secretary—Chemical Division) and Eng. Anna Warner who assisted me in editing this magazine. Many thanks extended to Eng. Jonathan Chang (Vice Chair—Electrical Division) for his tech-savvy capabilities in acting as our Webmaster. I would also like to acknowledge the efforts of Eng. Suzette Baptiste (Public Relations Officer) in assisting in whatever way possible to obtain articles and give suggestions about the magazine. It was all greatly appreciated.

APETT graciously welcomes its regular readers as well as its new readers. To contribute in discussions, join our LinkedIn group or keep updated with activities by visiting our website at www.apett.org. Engineers across all Disciplines, both within the Industry and Academia, are invited to contribute to our Magazine. To submit articles or for further queries, please contact us at: magazine-editor@apett.org or chemical-chair@apett.org

I look forward to continue working with APETT. Enjoy this edition and look forward to more technical content in December 2016 Magazine!

Eng. Julio Bissessar is currently a Graduate Trainee Process Engineer at Atlantic LNG. Julio has over one year work experience between Atlantic LNG and Petrotrin. He holds a Masters of Engineering (M.Eng) in Process Engineering from the University of Trinidad and Tobago (UTT) and has topped his year in Engineering.

Julio has also participated in a number of engineering related competitions. These include winning with his group (Eng. Laura Lewis and Eng. Shameal Ali) the BP’s Ultimate Field Trip (UFT) International Engineering Competition of 2014, winning a special prize for the senior category of the NIHERST’s Prime Minister’s Awards for Scientific Ingenuity of 2015 and a runner up for the IET’s Present Around The World (PATW) Engineering Competition of 2014/2015. Julio has also won the best design project at the Bachelor’s level (2013) and the M.Eng level (2015) at UTT. He has also presented at the Oil and Gas Technical Conference of Trinidad and Tobago 2014.
Message from APETT’s President
Eng. Fazir Khan

After only three months in this new 2016/2017 term, it gives me great pleasure to introduce the very first issue of our bi-annual publication of the APETT Engineering Magazine. I must commend the efforts of the new APETT Council for not only initiating this venture to offer a different high quality product to our members, but I also salute the dedication and diligence of the Editorial Team headed by Eng Julio Bissessar (Editor) and Eng Anna Warner (Chemical Division Chair). Ample guidance and support has been provided by Eng Suzette Baptiste, our very able and hard working PRO on Council.

By way of background on the Engineering Magazine, the new APETT Council identified the need to create a space for more ongoing technical input from and for our membership in direct contrast to the Professional Engineers’ Newsletter PEN, which is also published by APETT on a monthly basis with the mandate of the latter being to report to our membership on the activities of APETT. On the other side of the spectrum, this Magazine is not intended to compete with the annual production of the very technical Journal Of The Association Of Professional Engineers Of Trinidad & Tobago (JAPETT) for which the Editor in Chief is Prof Kit Fai Pun (UWI) and the review process is appropriately rigorous.

It would be remiss of me not to point out that this Engineering Magazine is fashioned after the pioneering efforts of the Chemical Engineering Division to produce the Chemical Engineering Newsletter back in 2011/2012. The main drivers of that effort being Eng Dr Haydn Furlonge (APETT President 2014/2015) with committed support from Eng Imtiaz Easahak.

It is therefore heartening to see the cross-divisional multi-disciplinary inputs included in this inaugural issue of the Engineering Magazine including sub-disciplines like Biomedical Engineering, that was not part of our organization before 2014. This is testament to our eagerness to change based on the changing needs of our environment and circumstances, as we actively seek to fulfill our mandate to promote engineering in Trinidad and Tobago. It is noteworthy to add in the face of trying economic challenges, that these online productions are achieved at zero costs to the organization, except for the invaluable volunteer efforts by our engineers.

To our members, I want to not only encourage your submission of papers to the Editorial Team for the sake of information sharing, knowledge transfer and publishing, but I also want you to contribute to the process and product, by providing feedback via our new website link at : http://www.apett.org/home/contact-us.

It is imperative that as professional engineers at all levels; our skills, training and practice in mathematics and applied sciences must be matched or even surpassed in this new era of information, by our ability to effectively communicate as we seek to continually improve ourselves and by extension our profession, during the entire course of our professional development and indeed our careers.

Sincerely
Fazir Khan
Process 

Design 

Improving 

Costs 

Reactors 

Engineer 

Experience 

Designing 

Chemical 

Processing 

Million 

Catalyst 

Optimization 

Managed 

Classes 

New 

Two 

Petroleum 

Nashville 

Maintenance 

Contractors
What is a Bow Tie Diagram?

A “Bowtie” diagram is a simple illustrative tool used for communicating risk. The completed diagram is shaped like a bowtie, and shows the relationship between a hazard, its causes, potential consequences, and controls or barriers in place to minimize the outcome if a major accident or top event were to occur.

The Bowtie starts by selecting a hazard, which is anything with the potential to cause harm in terms of human impact, the environment, or damage to property. Bowties can be developed by using existing risk assessments or conducting a Bowtie workshop with a multi-disciplinary team. Figure 1 below demonstrates a bowtie diagram for driving a car - a typical hazard encountered by the average employee.

![Figure 1: Simple Bowtie Diagram](image-url)
Benefits of Bowtie Diagrams

There are several benefits to using bowtie diagrams for communication of risk. Bowties can be used for training as they are easily understood by personnel at all levels in an organization. A bowtie shows the big picture while allowing users to see which safeguards are critical for preventing a cause from escalating to a top event (proactive) or mitigating consequences (reactive) such as fires and environmental impact, if the top event were to occur. It can also be a useful tool for Incident Investigations.

At a high level, bowties can highlight areas where an organization’s barriers and controls are weak i.e. inadequate or non-existent. This enables the organization to effectively focus risk reduction efforts where they will be most impacting.

Barrier Management

The prevention and mitigation controls identified are linked to individuals, work activities, and procedures, demonstrating the critical connection between barriers or controls (people, plant or process) and the management system for assuring their effectiveness.

On a more detailed level, bowties can be used to illustrate potential defeating or escalation factors that undermine barrier health. A defeating or escalation factor is a condition that reduces the effectiveness of a barrier, preventing it from providing the necessary assurance in the event of an accident. Escalation factors can be caused by human factors, mechanical failures, abnormal conditions or loss of critical services e.g. power, instrument air. For example, if an emergency exit door opens and closes automatically, an escalation factor can be a power outage or battery failure. This renders the door non-operational when required.

Use of Bowties at your organization

The bowtie methodology can be used for risk analysis in several applications, including safety, projects, security, quality, and business interruptions. Bowties can be used to communicate operational hazard and risks, risk to project delivery and management systems gaps.

As seen, the possibilities for using bowtie diagrams are endless. The bowtie methodology is a versatile and effective approach for managing and communicating risk in any organization. It shows a clear link between hazards and critical control measures, and provides a visual reminder of the need to ensure our safety management systems are robust.
Chemical Engineering: Mathematically Modelling a 3-Dimensional Glass Forehearth System for the Processing of Glass Bottles

By: Eng. Julio Bissessar, B.A.Sc., M.Eng, AMIChemE, AMAPETT
Graduate Trainee—Process Engineering

One of the major challenges of glass bottle processing is deducing a way to safely predict the gob temperatures and weights as it is forced through the orifice by the plungers and cut by the shears. These gobs are in the molten glass state. Predicting gob temperatures and weight at this particular point can be done using either a statistical approach or a modelling/simulation approach. The statistical approach would require operators to provide sample gob temperature readings at certain time intervals as the gob falls after being cut with the shears. From observation, this process is quite hazardous and increases the risk of injury to personnel. Therefore by creation of a simulation to predict the gob weights and temperatures developed in MATLAB, this may reduce the risks associated with measurements of physical properties of the gobs.

In order to successfully mathematically model a system to actively predict the gob weights, the entire forehearth section would need to be modelled. This forehearth section consists of both a channel (Section 1 in figure 1.0) and a spout bowl section (Section 2 in figure 1.0). Due to the complexity associated with the actual mathematical modelling though, only the forehearth section was modelled.

The glass forehearth section splits from the distribution section which is directly downstream of the furnace section. Its sole purpose is to condition the molten glass such that once the gobs form, the subsequent forming and cooling processes can be carried out effectively to produce a glass bottle that is free from defects as well as durable.
The forehearth section, commonly regarded as the conditioning zone, it involves both heating from burners and cooling from air coolers at certain intervals along its length. The figure below represents a 3-dimensional representation of the glass forehearth:

![3-Dimensional representation of the Glass Forehearth section](image)

**Mathematical Model of Glass Forehearth**

The mathematical modelling of the forehearth involved obtaining equations from a variety of journal articles and theses; namely, the two main sources were from Sina Pekcelen (1969) and Manoj K. Choudhary (1991). When modelling the flow of molten glass through the channel, certain assumptions were made; these assumptions were:

- Molten glass can be considered as an incompressible Newtonian fluid; simply put, an incompressible Newtonian fluid experiences minimal changes of density with respect to temperature.
- Molten glass is optically thick
- Molten glass is diathermanous; diathermanous materials/fluids are those which possess the ability to give off radiant heat
- The channel under consideration will be regarded as being symmetrical; thus, the placement of burners on one side of the forehearth will be mirrored at those specific positions on the opposite side of the forehearth

Other mathematical equations taking into consideration Navier-Stokes and Stokes equations for fluid flow as well as other velocity and temperature relationships were obtained from other theses prepared by Carol Elizabeth Humphreys (1991). The following equations represents the mathematical model of the forehearth system.

**Dynamic Energy Equation (Governing Equation)**

\[ \frac{\partial}{\partial y} \left( k' \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left( k' \frac{\partial T}{\partial z} \right) - \frac{\partial}{\partial x} \left( V_x \rho C_T \right) = \rho C \frac{\partial T}{\partial t} \]

where \( \theta \) represents time

(Pekcelen, 1969)

**Density relationship with temperature:**

\[ \rho(T) = \rho_0 [1 - \beta(T - T_0)] \] in kg/m³

(Pilon et. al, 2006)

**Viscosity relationship with temperature:**

\[ \log_{10} \mu = A + \frac{B}{T - T_c} \]

(Humphreys, 1991)
Specific heat capacity relationship with temperature:
\[ c(T) = \frac{218667T + 138.12}{0.00146T + 0.6012} \] (Pilon et al., 2006)

Reynolds number relationship with temperature:
\[ \text{Re} = \frac{\rho U_d L}{\mu} \exp\left(\frac{A + \frac{B}{T_{\text{max}} - T_{\text{min}}}}{T_{\text{max}} - T_{\text{min}}}\right) \] (Humphreys, 1991)

The dynamic energy equation would represent the temperature time profile which has been generated in the results section of this article. However, for MATLAB to properly execute, the boundary conditions of the system needs to be defined.

### Boundary Conditions

![Figure 4.0](image)

For the left and right walls as well as the bottom of the forehearth channel (based on convective heat transfer phenomenon):

- \[ -k_{\text{eff}} \left( \frac{\partial T}{\partial z} \right)_{z=N_z} = h_w(T_a - T) \]
- \[ -k_{\text{eff}} \left( \frac{\partial T}{\partial z} \right)_{z=1} = h_w(T_a - T) \]
- \[ -k_{\text{eff}} \left( \frac{\partial T}{\partial y} \right)_{y=1} = h_b(T_a - T) \]

With reference to the figure above, the following methodology represents the temperature distribution:

- \( T @ x=0 \) and \( y \) and \( z = 0 \) —— Temperature in the Initial Plane
- \( T @ y=d \) and \( x \) and \( z = 0 \) —— Radiating Boundary (surface of molten glass)
- \( T @ y=0 \) and \( x \) and \( z = 0 \) —— Bottom Temperature Distribution
- \( T @ z=w \) and \( x \) and \( y = 0 \) —— Side Wall Temperature Distribution

(Pekcelen, 1969)

The Boundary Conditions (B.C.) are as follows:

\( \left( \frac{\partial T}{\partial z} \right)_{z=0} = 0 \) (B.C. at centerline of forehearth)

(Pekcelen, 1969)

With respect to the radiative boundary at the surface of the glass when \( y=d \), it involves both radiative and conductive heat transfer. The equation is as follows:

\[ \left( \frac{\partial T}{\partial y} \right)_{y=N_y} = F_{SG}\sigma \left( T_{\text{surroundings}}^4 - T_{(i,j,k)}^4 \right) + h_c \left( T_{\text{gas}} - T_{(i,j,k)} \right) \] (B.C. surface of molten glass)

(Choudhary, 1991)
Results from Math Model

From successfully completing both the main file as well as the ode file utilizing MATLAB, a series of graphs were obtained. From the simulations, we obtained graphical results based on the sensor positions for each of the zones and three dimensional plots of “snapshots of time” within the channel.

The graphs generated predict the temperatures at the left, right and center (middle) temperature sensors as they are strategically placed in the forehearth. The x position indicates the length in meters along the forehearth channel. It can be clearly observed that the molten glass is cooled from the cooling air as the time increases for further processing to be molded as glass bottles.

The 3-D graph depicts the appearance of the temperature profile at the surface of the molten glass in the forehearth channel. It can be observed that there is a large step change observed at around 1.0 m onwards in the bed. At this particular point, the cooling air is introduced into the forehearth section which causes direct air cooling by convection (recall the boundary condition associated with the molten glass surface). This directly results in the sharp decrease in the temperature. Other graphs and sensitivities were done but were not included in this article.

Conclusions

This article served as a basic overview of the mathematical model of a glass forehearth in glass bottle manufacturing plants. Essentially, it takes into consideration energy balances and heat transfer phenomenon since the unit operation itself exists to condition the molten glass at particular temperatures to ensure proper molding and forming of the glass bottles. This model can be a great tool for use by glass bottle processing plants to predict temperature profiles along the lengths of the forehearth section to ensure that the process is functioning optimally.
Overview

Pressure Safety Valves (PSVs) are included in the design of processing facilities to protect assets such as piping and vessels by relieving system pressures during abnormal plant conditions. PSVs are safety-critical devices, and there may easily be hundreds of them installed on a plant depending on the size and complexity of same.

Given their importance, a robust maintenance and sparing strategy is needed for these assets – however, the difficulty lies in keeping track of and leveraging these specifics to draft the maintenance and sparing requirements. There are, of course, cost implications when this is done poorly, including the inefficient utilization of maintenance resources as well as having to manage unnecessarily large and diverse spares inventories.

This article discusses a few considerations for PSV sparing.

Data & Informational Requirements for Maintenance & Sparing

The PSV’s installed/operating environment should dictate its maintenance and sparing requirements – which makes sense. A PSV unsuitable for the installed service demands that much more attention than one that is - and it is relatively easy to end up in that situation owing to errors in PSV sizing or having unconsidered relief scenarios (for example). Figure 1 (below) lists a few of the data and informational needs to support this approach.
The Installed/Operating Environment

PSV requirements regarding the installed/operating environment are determined using the design basis, periodic design reviews, HAZOP studies, operating and maintenance histories, and root-cause failure analyses (among others). Any change to the PSV or its installed/operating environment should prompt reviews of the design, selection, set point, or maintenance and test procedures and associated frequencies.

The Asset

The most tedious part of the sparing exercise usually involves compiling and consolidating the requisite PSV data and information. The facility’s Engineering, Procurement, and Construction (EPC) contractor may have already provided a list of all installed PSVs as well as their components, which usually is a good starting point. Please refer to table 1 (below) as an example of a partial component listing:

<table>
<thead>
<tr>
<th>PSV#</th>
<th>Serial #</th>
<th>Model #</th>
<th>Size</th>
<th>Gasket Kit</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSV-001</td>
<td>S001</td>
<td>M001</td>
<td>1D2</td>
<td>G001</td>
<td>SP001</td>
</tr>
<tr>
<td>PSV-002</td>
<td>S002</td>
<td>M001</td>
<td>1D2</td>
<td>G002</td>
<td>SP001</td>
</tr>
<tr>
<td>PSV-003</td>
<td>S003</td>
<td>M005</td>
<td>1.5D3</td>
<td>G0328</td>
<td>SP008</td>
</tr>
<tr>
<td>PSV-004</td>
<td>S004</td>
<td>M002</td>
<td>1D2</td>
<td>G080</td>
<td>SP002</td>
</tr>
<tr>
<td>PSV-005</td>
<td>S005</td>
<td>M004</td>
<td>1D2</td>
<td>G088</td>
<td>SP008</td>
</tr>
<tr>
<td>PSV-006</td>
<td>S006</td>
<td>M010</td>
<td>1D2</td>
<td>G132</td>
<td>SP008</td>
</tr>
<tr>
<td>PSV-007</td>
<td>S007</td>
<td>M089</td>
<td>1D2</td>
<td>G005</td>
<td>SP001</td>
</tr>
<tr>
<td>PSV-008</td>
<td>S008</td>
<td>M001</td>
<td>1.5D3</td>
<td>G001</td>
<td>SP001</td>
</tr>
<tr>
<td>PSV-009</td>
<td>S009</td>
<td>M002</td>
<td>1.5D3</td>
<td>G080</td>
<td>SP002</td>
</tr>
<tr>
<td>PSV-010</td>
<td>S010</td>
<td>M198</td>
<td>1.5D3</td>
<td>G008</td>
<td>SP009</td>
</tr>
</tbody>
</table>

In this instance, only ten PSVs are listed here, but there may be several more installed on other sites - which would render the corresponding PSV listings more tedious to analyze. Concerning the example presented here, it would be useful to know the type and quantity of each spring or gasket kit installed for a given model of PSV (see figure 2); so that the appropriate number of spares are stocked accordingly for both planned and unplanned overhauls.

Figure 2 - Analysis of PSV Installed Base & Components
The analysis could easily identify and summarize the number of distinct PSV models and their components installed across the facility. It is advisable to consult the Original Equipment Manufacturer (OEM) if this data compilation or review occurs some years after the original installation to flag any obsolescence issues or standardize the components where possible.

**The Sparing Strategy**

The sparing strategy should take into account the existing installed base, as well as the lead time for purchasing new spares. Table 2, below, summarizes a few approaches worth considering:

<table>
<thead>
<tr>
<th>Approach</th>
<th>Considerations</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole-Body Replacement</td>
<td>Difficulty associated with servicing a given PSV (maintainability)</td>
<td>Reduces time to normalize the system</td>
<td>High inventory costs if several PSVs stocked, efforts should be made to standardize PSVs where possible to minimize inventory costs</td>
</tr>
<tr>
<td></td>
<td>Time constraints</td>
<td>PSV overhauls conducted during normal hours at an easier pace</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Several PSVs of the same model are installed but are swapped out in turn on a phased basis (example: for five identical PSVs requiring servicing every five years, one PSV can be replaced each year for five years — hence, only one spare is required)</td>
<td>Overhauled PSVs re-used as spares</td>
<td></td>
</tr>
<tr>
<td>No. of Component Spares Calculated as % of Installed Base</td>
<td>The analysis should highlight common PSV spares</td>
<td>Lower inventory costs owing to minimal spares stocked</td>
<td>Improper consolidation or analysis of PSV components may result in unnecessarily high stock levels</td>
</tr>
<tr>
<td>No Spares Stocked</td>
<td>Ease of sourcing spares on demand</td>
<td>Reduced inventory management costs and overhead</td>
<td>Highly dependent on the supplier to deliver spares in a timely fashion</td>
</tr>
<tr>
<td></td>
<td>Low criticality applications</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If a maintenance schedule calls for overhauling 100 PSVs in 2016, then at a minimum, 100 gasket kits are required for that activity. Such would, in no way, take away from the % of gasket sets stocked to address unplanned failures. Additionally, if PSV maintenance and sparing activities are contracted to a third party, the information presented in this article would still be necessary for the analysis.

**Conclusion**

Industries spend considerable amounts to purchase spares in a bid to manage downtime duration and logistical costs, and typically, such activities tend to be sub-optimized. The associated inventory costs include expertise and skills, labour, maintaining controlled environments, spacing allocations, and the like. Improper inventory management results in difficulty to locate spares, spoilage of perishable items, unnecessary stockpiling, and hoarding of material items, all of which are wasteful.

Sparing strategies are not necessarily repeatable across different sites because these would depend on the governing maintenance philosophies - this is why the necessary data and information to support the analysis are necessary to maximize the value of such initiatives.
Mechanical Engineering: Improving the Access Scaffolding Industry in Trinidad and Tobago


Introduction

Access scaffolding is perhaps one of the most important trades in the construction industry today, as many trades depend on access as a safe means of executing their work. Construction and Maintenance projects are typically expensive and technically demanding often involving large and diverse project teams.

The provision of access is critical to safe work and in many cases if properly executed, can allow the user trades to complete their work more efficiently. Furthermore, scaffolding plays a critical role in jobsite safety through minimizing lost work time from accidents.

According to OSHA statistics, scaffolding accounts for approximately 40% of all construction accidents. Construction work is inherently more hazardous than most other occupations and most accidents involve persons falling and occur during work performed from scaffolds. Collapse of temporary structures and falling materials also account for many fatalities. Many of these accidents can be avoided by the establishment of procedures and regulations to enhance safety. Many of the safety hazards are specific to the different job classifications, and typically scaffolding workers underestimate the hazards in their own work.

Review of the Scaffolding Industry

The scaffold industry in Trinidad is generally influenced by the US OSHA standard, the British Standards and the Australian standards to a lesser extent. In the upstream oil and gas, where there are operators from the United Kingdom, the requirement is the British standards. In the downstream industry, there are a greater number of companies with alliance to the United States, and consequently, the US OSHA standard is the prevailing standard.

There have been several scaffold accidents which have been reported in the local newspapers of persons who sustained serious injury and deaths. These accidents point to a general lack of regulation and enforcement on the part of the industry and the government. While the OSH agency of Trinidad and Tobago is responsible for investigating accidents, the agency is understaffed and in many instances, cases of non-compliance with the relevant codes and practices remain unchecked.
Scaffold failures occur for a variety of reasons and when analyzed, it has been found that there are a num-
ber of factors involved, with the root cause being the non-compliance with international standards. These
factors can be divided into four (4) major categories

The first category is an improperly designed scaffold and complete disregard for the scaffolding manufactur-
ers’ recommendation for use. The consequence of using a scaffold in an application other than its designed
capacity can be catastrophic due to overloading and transfer of loads. In commercial construction projects it
is common to see poorly constructed scaffolds being used, typically with one or two planks being used as
working platforms, missing guardrails and toe boards and invariably, little or no bracing.

Secondly, the use of substandard equipment is also prevalent in the industry. It is common to see inferior
materials and equipment being used instead of the certified and proper equipment.

Among these issues, the substitution of construction grade planks instead of scaffold grade planks is most
prevalent. Also, ranking close behind is the use of typical two (2) inch steel water pipes of schedules 40 and
20 being used for scaffolding, instead of the approved scaffolding tube bearing that marks of the relevant
standards, BS1139-6:2005, metal scaffolding.

Scaffold planks must also bear the stamp of quality from the appropriate testing agency, which conforms to
BS 2482:2009 specifications for timber scaffold boards. The use of construction grade planks on scaffolds
violates OSHA standards and constitutes an unsafe practice. Scaffold planks are available in two varieties-
solid sawn timber from specially grown timber species and manmade planks which comprise of spruce ve-
neers and adhesives for improved strength and durability and which reduce warping and splitting.

Thirdly, is the lack of appropriate certified scaffolding training and assessment. Currently, training is deliv-
ered in accordance with either the British standard or the OSHA standard. This has caused controversy as
to which one is better as the costs are quite different. Typically, scaffolders often pay for their own certified
training with costs that range from 2-6 weeks wages. The National Training Agency (NTA) of Trinidad and
Tobago, which is the agency responsible for training, has recently developed National Occupational Stan-
dards (NOS) for the scaffolding industry which will be used for the assessment of competencies in scaffolding.
This assessment places emphasis on the scaffolders’ ability to erect scaffolding in accordance with the occu-
pational standards, rather than knowledge testing alone as typical of the other types of training. The compe-
tency assessment programme, through the NTA will also maintain a database of all competent workers and
this will provide the proof of competencies.

Fourthly, is the lack of scaffold inspection performed by authorized and competent persons. OSHA states
that scaffolds must be inspected by a competent person at the beginning of every work shift. The British
Standard on the other hand states that the scaffold must be inspected every seven (7) days or after inclem-
ent weather. Scaffold inspection is critical to reduce the number of accidents in the industry. Ideally, inspec-
tion should commence when the equipment is delivered to the site together with the training records of the
scaffolders who will be erecting the scaffolding. This will identify the problems before the actual scaffold
erection commences. The premise here is that if the equipment is substandard and the workers’ compe-
tence cannot be proven, then there is no chance that the scaffold will meet the requirements of the stand-
ard. When the erection of the scaffold is completed, the inspector will perform the inspection visually and
utilize a checklist to easily record any non-compliance with the standard.

It is apparent that there exists a gap in the local industry for the provision of access scaffolding consultancy.
In most cases, even the major construction and maintenance companies do not have in-house expertise and
only recognizes the need for technical support when faced with imminent project delays and client dissatis-
faction.
ELECTRICAL ENGINEERING
Looking towards the future and a sustainable future at that, electricity is a necessity especially in the technological era we live in. However, according to the International Energy Agency (IEA) 1.2 billion people are without access to electricity and more than 2.7 billion people are without clean cooking facilities. In this, 80% of these people live in rural areas. If current policies do not change, by 2030 there will still be 1.2 billion people without electricity according to the IEA. Hence, urgency should be placed on rural electrification. A solution does exist in the foreseeable future which makes use of modern renewable energy technologies (RET).

Whilst fossil fuels are still readily available we cannot rely on this to last over a long period of time and so there is the need to invest in the future. One RET worth investigating is the implementation of mini-grids, which are fed by hybrid power systems. Mini grids are not connected to the national grid and can provide electricity generation at a local level, meaning a village-wide distribution network. Mini grids can be supplied by all sorts of energy, however, focus would be placed on the renewable energy as the primary source. Wind, solar and hydro can be used thus eliminating the need for fossil fuels. Fossil fuels would be used as a backup resource but it is very unlikely that it would be needed. Hybrid power systems are more than capable of supplying modern domestic needs such as lighting, communication, and water supply.

By: Eng. Matthew Kurbanali, Electrical Engineer
The previous image shows a DC/AC configuration. All the electricity components are connected to the DC bus line, thus charging the batteries directly, making the system very efficient. One aspect to bear in mind is the use of the different renewable technologies that are connected to this system. This is what makes this system versatile. Each renewable energy which is connected makes up for the dis-advantages of the other. Also, it makes the system adaptable based on geographical location as not all renewable energies are available. Based on systems that have already been implemented, a mini-grid usually use low AC voltage (220 or 380V) and have an installed capacity of 5-300kW. However, this is not the limit as bigger systems do exist.

According to the American Society of Mechanical Engineers (ASME), the establishment of off-grid hybrid systems will grow to more than 84,000 annually in 2020. The reason for such growth is due to the payback period which is estimated to be between 1-5 years. One such case study is a system installed at a coastal location in China for the Chinese Navy to power a communication tower. They combined both wind and solar, and are currently saving approximately $30,000 a year. Another such case is that of Verizon Wireless off-grid telecom site which has a fuel saving of $8300.00 annually with a payback period of 4.7 years. According to Mateo Chaskel of Urban Green Energy, “Throughout the winter, they did not use a drop of fuel on site, and they are currently working on expanding this project to other off-grid sites in California.” There was also a case study done to electrify a rural village in Lao, Ecuador. This system made use of a 12kW small hydro generator with a 2KWP PV system and a 15kVA diesel generator which supplied a 3 phase grid. This mini grid fed 105 households and works almost entirely on renewable energy. With the extra power being provided the national electricity provider connected the regional grid to the mini grid thus providing a revenue for the village as it sells electricity to the regional utility. This in turn has a positive impact on socio-economic factors.

In Trinidad and Tobago this system can be implemented and also serve as a solution, as there are many people who live without electricity. It may seem costly to implement as cost of diesel is cheap but when looking at cost we should look at that on a Life-Cycle basis. Fuel charges can increase and also cost of delivery of fuel exist, whereas the generation costs with RET are fixed and upfront and also decreasing. A hybrid system such as the one shown in the image above last between 20-25 years with regular maintenance. This system provides clean energy and allows for movement towards sustainable development of Trinidad and Tobago.
Multiple Model Predictive Control Bridging the Information Gap to Regulate Highly Non-Linear Processes Part I: Regulating the Cardiovascular System

By: Eng. Dr. Brian Aufderheide¹, Eng. Makeda Wilkes and Eng. Adrian Lutchman, Process Engineering at UTT

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Prologue
After nearly a year of preparation the day had arrived for our first dog experiment. Our objective was to automate the control of blood pressure and blood flow of a patient in surgery or critical care. We started off simply enough with a single shot of phenylephrine, and the response was just how it is predicted in our often cited model done by our research group (Gringrich and Roy, 1991). We waited thirty-five minutes and gave another shot of phenylephrine to see if the same response would occur. This time it was a mirror image the blood pressure initially dropping in an inverse response before going up to a final elevated higher pressure than earlier. Our model could not do that… our model failed to accurately predict the dog’s own control responses to a change in blood pressure. This failure made it clear that our model could not be depended on to provide accurate predictions for our Model Predictive Controller. We cancelled the rest of the day and the following week of experiments. We had only two weeks to come up with a new controller design.

Introduction
Here we will summarize the work done on Multiple Model Predictive Control, Doctoral Thesis work done by Brian Aufderheide (Aufderheide, 2002). It is critical to understand that this came about out of sheer desperation and that it was done under difficult time constraints of two weeks. Control was boiled down to the essence: what is the minimal needed model for adequate control? A First Order Plus Dead Time (FOPDT) model which has process sensitivity, the dominant time constant or dynamics and a dead time to account for not only true transport delay but also any inverse response. A bank of models then and some way to select the best one or to blend them together as a weighted average was required, a Bayesian Recursive Algorithm. And so a new controller was developed and surprisingly it worked amazingly well.

To obtain a better understanding on how the new controller worked so well, an in silico study was done with the Van de Vusse reaction system which has input multiplicity, gain sign changes, and inverse responses: this will be the second part of this article.

Model Predictive Control (MPC)
MPC is a control algorithm that is analogous to playing a computer in a game of chess (Fig. 1).

This paper outlines the work done on the dog experiments and the subsequent pig experiments from consultation work with Baxter Healthcare Corporation.

Figure 1: Model predictive control (Rao et al, 2001)
At the top of Figure 1, the current sampling instance k, a model is used to predict the output behavior of the system, P sample intervals into the future, based on the past states and M future control moves. The future control moves are optimally estimated to minimize predicted error from the set point. Feedback is achieved by implementing only the first of the M moves. At the bottom of Figure 1, based on the actual measurements of the output at the (k+1)th instance, the model predictions are corrected as an additive disturbance to account for model mismatch and unmeasured disturbances. The optimization procedure is repeated in a receding horizon framework to compute a new set of moves (Rao et al, 2001).

**Multiple Model Predictive Control**

If a first principles model exists, the standard approach is to update parameters online using an Extended Kalman Filter (EKF). However, the serious limitation to an EKF is that the number of parameters estimated cannot exceed the number of measured outputs (Kozub, MacGregor 1992). To get around the information limitation, a multiple model adaptive estimator is used to obtain a prediction model for MPC (see fig. 2). Model bank can be varied by feed concentration, dilution rate, kinetic parameters etc. The bank of models can be step response models, as used in Dynamic Matrix Control (DMC) or state space models (linearized models from fundamental ordinary differential equations). The key here is that you are providing additional information for the final prediction model. If the system responses lie within the existing model bank, then it will work well. Information requirement is similar to fitting only one parameter since we are requiring the algorithm to choose one model out of the bank. The final prediction model can be a weighted average (blended) model or be a winner takes all highest weight model as prediction to MPC.

MPC Equations:

A general form of the optimization problem at time step k is:

\[
\min_{\Delta u(k+1), \Delta u(k+M-1)} \sum_{i=k}^{k+P} e^T(\bar{i})Qe(\bar{i}) + \sum_{i=k}^{k+M} \Delta u^T(\bar{i})R\Delta u(\bar{i})
\]

objective function to minimize w.r.t. \(\Delta u(k+1..M)\)

where \(e(\bar{i}) = r(\bar{i}) - \hat{y}(\bar{i})\)

The predicted and corrected prediction models are:

\[
\hat{y}(k) = \sum_{i=1}^{N} S(i)\Delta u(k - i) + S(N)u(k - N - 1)
\]

\[
\hat{y}^c(k) = \hat{y}(k) + d(k)
\]

where \(d(k) = y(k) - \hat{y}(k)\) is the constant additive disturbance

The weights are assigned by a Recursive Bayesian algorithm. The assumption is that the bank of models contains the “true” model out of a population of models where their residuals (error to actual measured output(s)) is normally distributed. The Recursive Bayesian theorem for the kth step and ith model is (Aufderheide and Bequette, 2003):

\[
p_{i,k} = \frac{\exp \left(-\frac{1}{2} \varepsilon_{i,k} K \varepsilon_{i,k}^T \right) p_{i,k-1}}{\sum_{j=1}^{N_m} \exp \left(-\frac{1}{2} \varepsilon_{i,k}^T K \varepsilon_{i,k} \right) p_{j,k-1}}
\]

where residual for ith model:

\[
\varepsilon_{i,k} = y_{i,k} - \hat{y}_{i,k}^c
\]

The algorithm is computationally inexpensive and insures that probabilities are bounded from 0 to 1. An additional benefit is that poor models are rejected exponentially fast so having a very large number of models does not necessarily lead to a very large drop in controller performance. Large values in the convergence matrix, K, will magnify the residuals and cause an acceleration of model reduction to a single model. One issue though is that once a model obtains a probability approximately zero it is no longer available for use later on when it might be needed. To keep models alive in the bank an artificial cutoff, d, is used. For \(p<d\), the probability is reset to \(p=d\) and not allowed to go to 0.

---

**Figure 2: Multiple Model Predictive Control (MMPC)**
These models are excluded from being weighted such that
\[ W_{i,k} = \frac{p_{i,k}}{\sum_{j=1}^{n} p_{j,k}} \text{ for } p_{i,k} > \delta \]
\[ W_{i,k} = 0 \text{ for } p_{i,k} = \delta \]

**Cardiovascular System Regulation:**

The control objective is to regulate both blood pressure (Mean Arterial Pressure or MAP) and blood flow (Cardiac Output or CO) by the automated infusion of two cardiovascular drugs, sodium nitroprusside or phenylephrine with dopamine. The goal is to assist the Cardiac Nurse/Anesthesiologist in a surgical setting or in intensive care. Roughly 25 dog experiments were done, for complete set of results see Rao et al., 2003.

It is an ideal drug for congestive heart failure since it decreases both the preload and afterload so the heart has less blood to pump at a lower resistance. Phenylephrine constricts the arteries increasing the systemic vascular resistance which leads to higher blood pressure. In most experiments, due to causing congestive heart failure by high levels of halothane, SNP was used primarily with DPM to regulate MAP and CO. Phenylephrine was used more as a disturbance to be rejected.

It is critical that drug infusion constraints are met. For example SNP breaks down in the body to cyanide and high levels then are very toxic. Similarly dopamine is a natural neurotransmitter and must be maintained within certain concentration limits to affect the cardiovascular system and not the kidneys or brain.

A brief overview of the cardiovascular system and its regulation is in Fig. 3. MAP is directly related to cardiac output by the systemic vascular resistance (SVR). However, the higher the resistance the more difficult it is for the heart to pump blood through the arteries leading to a decrease in stroke volume and CO. The strength of a heart’s contraction is due to the number of crosslinkages present in the muscle (contractility). The drug dopamine (DPM) increases the contractility. The anesthetic halothane decreases the strength of the heart and was used to induce congestive heart failure temporarily in the dogs. The anesthetic isoflurane does not affect much the heart strength nor the Baroreceptor Reflex, the body’s own disturbance controller to regulate MAP.

The other drugs used in this study are sodium nitroprusside (SNP) and phenylephrine (PNP). SNP dilates the arteries decreasing the systemic vascular resistance which leads to lower blood pressure. SNP also increases the venous compliance causing the veins to stretch and hold more blood in reserve.

Figure 3: Cardiovascular System. Direct relation of MAP and CO is given: SVR is Systemic Vascular Resistance and \( P_{Ra} \) is blood pressure in right auricle. (Gray, 1977).

Figure 4: Dog Experiment – 1st Time with MMPC MAP control of hypertensive canine under isoflurane using (SNP). PNP was used to induce hypertension. (Rao et al, 2001).

The very first experiment using MMPC was done regulating only MAP with the dog under the anesthetic isoflurane (Fig. 4). The control is very good responding well to three set point changes and a disturbance in PNP administered to the dog. The dogs Baroreflex Receptor control clearly fights lowering the MAP by elevating Heart Rate (HR) and CO throughout the run. The MAP quickly increases by more than 30 mm Hg after SNP is no longer administered.
It was very difficult even with us having more than a dozen experiments of experience to choose physically realizable setpoints where MAP and CO could be maintained. This difficulty and the realization that Cardiac Nurses would not require a specific CO but more of a range that it lied within, had us develop soft penalties in the objective function so CO could be maintained within a band. Fig. 5 shows a run where CO is maintained within an acceptable band while MAP is kept at a specific setpoint. Note that PNP is again used to provide a disturbance to be rejected to test the controller further. Performance and robustness of the controller are very good. Note that the control was over four hours in duration.

Because of our success regulating MAP and CO in dogs described in journal articles and in several conferences, we were approached to do Small Business Research Grants and consulting work. Fig. 6 illustrates the first set of results regulating MAP in an awake and ambulatory pig done at Baxter Healthcare Corporation. What is impressive is how well the controller handles the initial model misinformation due to the drug infusion line not being primed prior to the experiment initiating. This causes an additional lag of three to four minutes, but the controller overcomes this very well and regulates MAP for roughly 20 minutes. Other experiments ran for much longer and included the pig actually eating food and also being sedated (Aufderheide 2002).

Overall MMPC was done on dogs and a pig using a set of First Order Plus Dead Time Model banks. These were generated with little data (since we simply did not have it!) which consisted of using drug insert data for humans and in the case of the pig three earlier short experiments (each stopped due to very poor control) done using a Fuzzy Logic Controller by a different contractor. Models were simply done by coming up with a wide range of gains, time constants and time delays that spanned the very limited data we did have. In general, MMPC worked great as long as the dog/pig response to the drugs was bounded by the bank. In the case of controlling MAP and CO the model bank was over 25,000 models! Yet due to the exponential rate of the Bayesian Recursive Algorithm only a handful to a dozen or so models had any real weight after 10 or so samples were taken.

Conclusions

There are often highly nonlinear systems that you cannot develop a detailed model due to its complication or a lack of data to fit all the parameters needed for the system. So what can be done? Develop a First Order Plus Dead Time model bank and use it as a Gray Box System Identification tool. The results are surprisingly good. In the second part of this article, will investigate more deeply why this is the case, and how FOPDT bank compares to actual step responses of different operating conditions, and first principle model estimation.
Trinidad and Tobago is once again in the throes of a tight fiscal situation. Revenues from the exploitation and export of oil and gas have fallen as a result of reduced global prices. The prognosis is for a sustained period of low energy prices due to increased global supply and the ascendancy of affordable renewable energy. The imperative to diversify the productive base of the local economy has regained the attention of the national planners.

One area that has been identified for investment and focus is the maritime sector. Accordingly, the 2016 Budget Statement cites “… given our location outside the hurricane belt, we are well placed to establish a viable and robust maritime economy.”, and “The maintenance support will emerge as a hub for major ship-repair and ship-building within the CARICOM region, thereby creating a New Maritime Economy.” (GORTT 2015) Over the last seven years several proposals for expanding the maritime infrastructure have surfaced. These have included dry-docks, ferries, service and transshipment ports and the decades old plan to relocate the Port of Port of Spain.

The maritime sector has always played an important role in facilitating trade and movement of goods. However, this importance has been increasing. The advent of trading blocs and the globalization thrust in the nineteen eighties has propelled the growth of international trade and by extension the shipping industry and the global sea borne trade. It is estimated that more than 80% of all international trade in goods is transported by sea. (UNCTAD, 2009). The Caribbean Region consists of geographically dispersed small island states where transnational terrestrial transport is limited and relatively un-sophisticated where possible. Transport is a key factor in the cost of inputs for small individual island economies that rely heavily on the importation of most goods to sustain their services oriented economies. This reliance on maritime transport is even truer for those economies like Trinidad and Tobago and Suriname that exploit process and export natural resources like oil and bauxite. In short the maritime transit of goods and passengers is inextricably linked to the success and fortunes of the Caribbean Region and Trinidad and Tobago in particular.

Efficient maritime logistics therefore plays an important part in inter-island trade as well as global trade for Trinidad. Weakness in the maritime logistics apparatus reflect directly on the level of competitiveness and by extension economic growth and national welfare. This is demonstrated within the CARICOM Region which suffers from sub-optimal maritime logistics. In this case inter-regional trade is characterized by volume constraints, high unit freight costs, multiple transshipment stops and limited frequencies of vessels. To compare, in 2007 intra-regional trade for the European Union countries was about 74%, while for CARICOM the estimated volume was just 16% (IDB, 2009).

This is not necessarily a factor of geography, but other important factors such as insufficient investments in port and transport infrastructure and logistics capabilities and declining productivity. Even within the Caribbean Region efficient movement of goods is possible where physical infrastructure and logistics systems are well developed. These routes however are limited.

Innovative approaches are therefore required to revamp the transport and general logistics capability within the CARICOM if sustainable expansion in local trade and services is to be realized.

There are two concepts to consider therefore as Trinidad and Tobago moves towards deepening its investments in the maritime sector - Investments in the physical civil and transport sector and investments in the logistics capacity to ensure the establishment of globally competitive freight handling and maritime services.
In the past, port competitiveness has relied principally on geographic location and its spatial relationship to landside or hinterland transport links and positioning. Major ports therefore were well connected to internal civil infrastructure including rail, highways and waterways.

However, the increased movement of goods internationally has been supported by innovations and large investments in engineering and logistics. These engineering innovations have included systems of containerization of cargoes, development of larger capacity vessels and information systems among others. Logistics on the other hand has emerged to maximize the utilization of the physical infrastructure to support the efficient movement of the increased volumes of international cargoes.

Logistics investments link the freight distribution infrastructures such as ports, terminals, real estate, and telecommunications with the actual transport operations using multi-modal options including road, rail and sea and the software or human resources expressed as labor, management, governance, and research and development. (IDB, 2012). The objective of such activities is to move goods from their origin to destination across international borders at the least possible cost in a specified time and for a given reliability (World Bank, 2012).

The increases in efficiency of maritime vessels and lowered freight costs have spawned a global distributed manufacturing eco-system. Cars for example are assembled in one country with major components from several other countries – the components scheduled to arrive at the final assembly point as and when required. This distributed production is supported by sophisticated tracking systems, automated warehousing and scale and scope concentration strategies that reduce costs, maximize profits and create competitiveness.

Ports can now no longer rely solely on expanding physical infrastructure and location advantages but must also apply industrial and electronic engineering to increase operational and managerial efficiencies and overall productivity of the maritime freight system (Le-Griffin Murphy, 2006).

**Focus for Further Investment**

Panama Canal -> +ve transformative impact
- Overcome scale + efficiency bottlenecks
- Increase Private involvement—PPP’s
- Improve Govt facilitative environment
- Integrate into value chain -> logistics
- Form strategies with local industry linkages
- Green & CC-DRM readiness
- Consolidate tacit knowledge -> Comp. Adv.

![Fig. 1: Vicious Cycle Low Productivity Trap](image)

In considering the expansion of the Trinidad and Tobago maritime sector therefore, several key market strategies will need to be considered. How does Trinidad and Tobago intend to position itself? What will be the market strategy? Some of the options presented include; a global transshipment player, a global maritime repair centre, a regional maritime transshipment centre or the reinforcement of its local and trans-border maritime service capability principally to support the extraction, processing and export of oil and gas from local fields and neighboring oil provinces in Guyana and Venezuela.

The focus will likely be on improving freight handling efficiencies and expanding the logistics infrastructure to lower inter-regional transport costs.

A more recent phenomenon is the offshore transshipment activity in the Gulf of Paria for global trade in primary materials. Vessels anchor offshore and materials are transshipped from one to another. This development does not use local physical infrastructure with the intensity of other transshipment methods. A technical review of this transshipment modality is required to determine the development impact on the local economy.
Other proposals have focused on Trinidad’s advantageous geographic location to support the entry into the global maritime market. Our ports are relatively close to the Panama Canal and to major international shipping lanes to eastern South America and Europe. This is underpinned by our long industrial sector experience and engineering capacity. Two major opportunities have been considered within this strategic context; ship repair and maintenance facility and transshipment/logistics hub.

The capacity to repair ships already exists on a limited scale locally. The grand opportunity here is to leverage local engineering capability and industrial skill experience to expand the ship repair and offshore platform fabrication sub-sector into a Regional and global business. Design and feasibility studies have already been carried out for the establishment of at least two world class facilities.

Both ports at Port of Spain and Point Lisas currently execute transshipment activity. While they are significant hubs for the Caribbean, they are not considered as global transshipment ports.

For both cases a global market strategy requires large scale investment in port and hinterland infrastructure and will provide significant stimulus for the local engineering and construction industry during the development and operation phase.

Challenges exist however. Other countries in the Caribbean Basin have already seized on this potential and have expanded current capacity or are nearing the completion of new ports with the required draught to transship large TEU capacity vessels. These include Costa Rica, Panamá, Dominican Republic, Colombia, Jamaica and Cuba. The global transshipment market is dynamic and extremely cost sensitive. Global transshipment is a risky business for the ports aspiring to this niche market -unless these aspiring ports have a significant inland freight traffic. Generally, transshipment traffic has no connection to the country in which the port is located. The risk of relocation of transshipment traffic to ports that are cheaper and more competitive is high, even if the original port location is preferable. This can result in stranded port and maritime assets and unserviceable and unsustainable debt.

One key element will be a paradigm shift from constructing port infrastructure as a standalone project to developing freight and services logistics networks that integrate production centres with consumption endpoints. The design of ports must prioritize links to internal transport and information networks and incorporate industrial, commercial parks within its extended hinterlands.

Another imperative will be the reversal of the decline in either labour and systemic productivity or Total Factor Productivity (TFP). The TFP of Trinidad and Tobago and the Region has been in steady decline over the last few decades. On the other hand, developed and emerging economies are recording increases in TFP largely driven by application of engineering innovation in production, tracking, logistics and safe and energy-efficient infrastructure. Technical solutions to guiding labour to be more productive by reducing re-work, and encoding tacit knowledge in production and services systems draw heavily on industrial and IT systems’ engineering capability.

A third consideration is the massive capital cost associated with such developments. For example, a global ship repair facility would require upwards of US$1 billion in investments. The continued demand for capital improvements to maintain transshipment hub competitiveness poses a challenge for most regional governments. These challenges have been addressed through sharing this investment cost and technology requirement with maritime freight companies, civil contractors and port and industrial park operators in joint public-private ventures. The modernization and expansion of Trinidad and Tobago’s maritime sector can be the next major industrial step change and economic transformer. Put another way, maritime sector development, if well considered, conforms to a model that can exploit the limitations of the Caribbean’s size, resource and geography to produce a globally competitive business (Jessop, 2015).

There are of course other critical issues to be addressed and opportunities to be explored as part of this process, of which this short paper has highlighted only a few.
Civil Engineering: The Use of Welded Wire Reinforcement in Reinforced Concrete Shear Walls

By Eng. Brendon Inniss, Senior Structural Engineer, BSc. R.Eng, MASCE, MAPETT

Abstract

Welded wire reinforcement (WWR) has proven to be an extremely versatile tool in reinforced concrete (RC) building construction when it comes to the construction of RC shear walls. The time and cost savings are simply too significant to ignore when compared to the option of manually fabricating and installing the rebar mats. A technical paper written by Riva and Franchi in May/June 2001 ACI Structural Journal concluded that RC shear walls reinforced with WWR does not perform well when subjected to cyclic loading. The contents of this paper have had a profound adverse effect on the local statutory agencies willingness to accept and approve building designs where the RC shear walls were reinforced with WWR.

The real question is – does WWR provide the required ductility that RC shear walls need for providing the necessary lateral load resistance and storey drift control for multi-storey buildings? Furthermore, how does WWR behave in a RC shear wall under the influence of in-plane lateral cyclic loading? Will the weld integrity be compromised due to the fact that the base metal properties of the wires/bars causes embrittlement under applied hot works? Moreover, how will the individual bars/wires behave within the zones of the boundary elements? These are certainly valid and reasonable questions to ask as convenience and economics cannot and shall not take precedence over structural integrity and life safety in public buildings. This article will seek to provide answers by referring to the applicable building Codes, Standards and even Journals.

Introduction

For years now, contractors in Trinidad and Tobago have been using concrete and/or clay blocks in building construction whether domestic or commercial. However, as the times changed, clients demanded more for less – the need for new innovative ways to build structures faster and cheaper became a necessity. Several construction techniques were implemented to not only satisfy client requirements, but to be more competitive in the public tendering of projects. One of these techniques was the construction of small buildings entirely in reinforced concrete (RC).

In the government housing sector, hundreds of housing units were built entirely with reinforced concrete with the exception of the roof. The slabs and walls of these houses were reinforced with welded wire reinforcement (WWR) affectionately referred to as BRC. This was utilized as a means of significantly economizing on time and labour costs associated with fabricating and installing the steel manually over multiple units. This construction method was utilized successfully at the Corinth, Cleaver, Oropune and Tarouba Housing Developments in Trinidad to name a few.

From housing units, the construction of multi-storey buildings entirely in RC became more prevalent with the aid of specialist formwork systems and an architectural design that facilitated the use of BRC as much as possible. When the design-build procurement practice became popular in Trinidad, it permitted contractors to become a main stakeholder in the architectural design process of the proposed building. Features such as floor to floor heights; column spacing/layout and so on would be decided early so as to guide the architectural design and permit BRC to be safely utilized in the slabs and especially in the walls. This was demonstrated in such buildings as, Parvati Girls Hindu College, Besson Street Police Station and COSTAATT Main Administration Building in Trinidad as well as Ocean’s Edge Villas in St. Kitts and Royalton Hotel Accommodation Building in St. Lucia.
Comparative Study

The eighteen (18) experimental test specimens evaluated in the paper by Riva and Franchi contained a combination of weldable steel reinforcing bars; a new kind of hot-rolled welded wire mesh and traditional cold-drawn welded wire mesh. The permutations and combinations were carefully managed so as to provide a very conclusive assessment of the samples. No mention was made of the weld strength of the cold-drawn welded wire mesh. It was mentioned however, that the hot-rolled welded wire mesh failure is characterized by weld detachment between the longitudinal and transverse bars. Seeing that cold-drawn welded wire mesh is what is manufactured and distributed in Trinidad, hot-rolled welded wire mesh will not be further discussed in this paper.

Riva and Franchi did in fact acknowledge that there is no objection to having WWR within the web of the shear wall due to the low strain demand (due to shear) in that region of the wall. Prior to entering into a detailed discussion of the results of the tests, Riva and Franchi made the following statement;

"…..Being that the cracks are mostly horizontal, it can be concluded that the wall response is governed by bending, with shear playing only a minor role. Mesh fabric proved to be an efficient means to control shear crack propagation. In fact, it was observed that inclined cracks formed towards the middle of the panel and near the load application point during the first two loading cycles, after which they stabilized and no further propagation and opening of inclined shear cracks was observed. This result is typical for all tested panels. The following discussion of the test results will be focused on the failure mechanism related to bending effects, while the influence of shear on the panels failure will not be discussed, as it appeared to have little relevance for the present tests.”

When loaded, the test specimen reinforced with cold-drawn WWR showed a brittle failure characterized by a single crack at the base of the wall, with plastic deformation localization in the base section reinforcement, resulting in a typical tensile failure of the bars with "necking" of the most stressed section. Essentially, the detailed study carried out by Riva and Franchi is stating that using WWR in the boundary elements of a shear wall should be avoided due to the fact that it is likely to fail under in-plane cyclic loading. Using traditional rebar with seismic cross-ties as per ACI 318 chapter 21 in the boundary elements is recommended to deal with this. Outside of the boundary elements, that is, within the web of the wall, the WWR performs well to control cracking due to the cyclic shear load.

Technical Assessment

Welded wire reinforcement is manufactured from bars to BS 4449 or wires from BS 4482 welded together to provide joints of specified shear strength in machines by a process known as electrical resistance welding. Electrical resistance welding involves the combination of heavy electric current (applied at low voltage) passed through the junction of wires combined with heavy mechanical pressure for a short specific time. Section 6 of the BS 4483: 2005 states that, "All welded fabric shall be factory made and machine welded. The joints, at the intersection of the longitudinal bars and the transverse bars, shall be made by electrical resistance welding to provide a specified shear resistance". Section 7.1 of the same specification states that "the chemical composition of the bars shall conform to the requirements of BS 4449: 2005". BS 4449 specifies the weldability requirements for all grades of steel, in terms of the chemical composition and in particular the carbon equivalent value.

According to BS EN 10080 - 2005 clause 7.1.1, the weldability of the rebar is dependent upon two characteristics (i) carbon equivalent and (ii) limitations on the content of certain elements. The maximum values of individual elements and the carbon equivalent shall not exceed the values given in Table 2 of that specification (see below).
Table 2. Chemical Composition (% by mass).

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition in WWR</th>
<th>Limiting Amount</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0.0480%</td>
<td>0.22%</td>
<td>OK</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.0011%</td>
<td>0.05%</td>
<td>OK</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>0.0015%</td>
<td>0.05%</td>
<td>OK</td>
</tr>
</tbody>
</table>

The bars to be used in the manufacture of WWR shall conform to the chemical composition outlined in BS 4449: 2005 clause 7.1; Table 2. This table is exactly the same as that shown in the figure above. This basically implies that WWR shall only be manufactured from bars or wires that can be safely welded i.e. with a carbon content that is low enough to avoid embrittlement.

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The chemical composition of the bars for the A193 BRC which was used to reinforce the RC shear walls is shown in figure 2.0 below:

From the figure above the carbon content of the WWR provided is well under limiting amount as per the BS 4449: 2005 specification. The minimum strength of the welded joints in WWR (35,000 psi) must satisfy the requirements of BS 4483: 2005 clause 7.2.4.

With reference to American standards, the rebar material used in welded wire reinforcement conforms to any one of the following standards:

- ASTM A82 (cold-drawn plain steel wire);
- ASTM A185 (welded plain steel wire)
- ASTM A496 (deformed steel wire) or
- ASTM A497 (welded deformed steel wire)
Bars that conform to ASTM A615 are not used to manufacture welded wire reinforcement because their chemical composition does not permit it unless carried out under the strict provisions of ANSI/AWS D1.4. In other words, welding of ASTM A615 bars lead to embrittlement of the steel which is not desired for the reinforcing of reinforced concrete sections subjected to seismic loading. However the ACI Code does permit the welding of crossing bars to facilitate fabrication or placement of reinforcement provided these bars are welded via welding operations under continuous, competent control as in the manufacture of welded wire reinforcement (refer to ACI 318-05 clause R21.2.7.2). A point to note is that the mechanical properties of the bars/wires used in WWR include ribs and weld shear strength - both of which contribute to the bonding of the WWR to concrete. Tests carried out by the Wire Reinforcement Institute demonstrated that the range of strain results at ultimate strength were 0.0075 - 0.0090 in/in, which shows that strain of both wire and welded wire at ultimate strengths are 2 to 2.5 times the ACI 318 requirement of strain to be 0.0035 in/in at minimum yield strengths. This shows that there is a substantial safety factor for wire and welded wire reinforcement.

Conclusion
For special RC walls (R = 5) reinforced with WWR in multi-storey buildings to be able to satisfy ACI 318 chapter 21 provisions on reinforcement, the structure should be modular and regularly shaped with shear walls that exhibit the following features:

- A low height to width ratio (ideally H/W < 1.0)
- Small or minimal openings
- Continuous from foundation to roof (no soft stories)

The tributary areas supported by closely spaced walls are small resulting in each shear wall resisting very low base shear forces. Low base shear forces on walls that possess high load bearing capacity equates to low strain demand in the web of the wall section. From a material property standpoint the following conclusions can also be made:

- The WWR manufactured locally is in accordance with BS 4483: 2005; which states that all bars/wires used to manufacture WWR must meet the requirements of BS 4449: 2005 in terms of chemical composition of the steel.
- The bars used to manufacture WWR can achieve yield strengths as high as 80,000 psi (552MPa) in shear and flexure, which is stronger than the traditional rebar 60,000 psi (414 MPa) ASTM A615 bars which are not weldable.
- The BS EN 10090: 2005 standard states that all bars/wires that meet the requirements of BS 4449: 2005 can be safely welded without compromising the structural integrity of the steel.
- Although the shear strength of the welds in WWR are deemed to be satisfactory, detachment of the welds linking the cross bars is not the typical failure characteristics of cold-drawn mesh. That failure mechanism is attributed to hot-rolled WWR mesh only which is not manufactured/distributed locally.

It is important to remember that when comparing WWR to traditional rebar in the RC walls, the ductility of the wall is heavily reliant upon reinforcement detailing – a fact which is pointed out by Riva and Franchi. One should also consider that subsequent to the findings by Riva and Franchi in 2001, there have been five (5) releases of the ACI 318 and none of them prohibited the use of WWR in RC shear walls. Therefore once the Code provisions are satisfied, there should be no objection to the appropriate use of welded wire reinforcement in reinforced concrete shear walls.
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