DEVELOPING SAFE SHELTER STRUCTURES

Anchors & Joints

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1. Introduction

Faculty of the Built Environment
- Dep. of Building Technology
  - Chair of Product Development (Prof. Lichtenberg)
    - Shelter research
      - Ir. Tim de Haas
      - Ir. Mark Cox
      - Dr. ir. Roel Gijsbers
- Actively involved in humanitarian sector since 2007
  - Symposium ‘Innovative Sheltering’ @ TU/e
  - Start of long lasting cooperation with Netherlands Red Cross
    - Research Fellow: Eelko Brouwer (NLRC)
- Evolved into cooperation with a variety of NGO’s and organizations
1. Introduction

- System design: modularity & packaging
- Shelters
- Facilities: water & sanitation
- Infrastructure: medical, energy, re-building
- Deployment & transport
- Demonstration

S(P)EEDKITS has received funding from the European Union’s Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 284931

www.speedkits.eu
2. (successful) Product Development

Possible routes

1. Out of the blue / brainstorm
2. Trial and error
3. Experience based design
4. Evidence based design
2. (successful) Product Development

What is needed? (in chronological order)

1. Well structured process planning
2. Clear picture of the stakeholders and their demands
3. Boundary conditions
4. Lessons from the State Of The Art
5. Design Brief

6. Creativity (concept designs)
7. Engineering & calculations
8. Testing (prototypes)
9. Re-engineering & re-calculations (final design)
10. Validation (pilot project)
2. (successful) Product Development

Step 1 to 5
- Situation analysis
  - Checking and adaptation of the boundary conditions
    - Enterprise
    - Project leader
    - Project
  - Go / no go

Step 6 to 10
- Strategy phase
  - Internal analysis
    - Strengths
    - Weaknesses
  - External analysis
    - Opportunities
    - Threats
  - Search fields
  - Product-market combinations
  - Organization process
  - Go / no go

- Creation phase
  - PMC’s
  - Generating Ideas
  - Selection
    - Feasibility analysis
    - Prototype
    - Development plan
  - Go / no go

- Development phase
  - Program of potential failure
  - Calculation
    - Drawing
    - Tests
    - Market tests
  - Pilot project
    - Feasibility
  - Go / no go

- Realization phase
  - Certificates
  - Education
  - Organization
  - Setup production
  - Promotion activities
  - Presentation / exhibition
  - Feasibility
  - Go / no go

- Market diffusion phase
  - Market strategy
  - Approach plan
  - Innovators first
  - Projects
  - Pilot project
  - Expansion
  - Evaluation

**Start of designing**
3. Engineering methods

1. Intuition
   - Tradition
   - Professional experience

2. Rules of thumb

<table>
<thead>
<tr>
<th>Structural element</th>
<th>Section and top view</th>
<th>Profile size</th>
<th>Span</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single layer</td>
<td></td>
<td>$d$ [mm]</td>
<td>$l$ [m]</td>
<td>$\frac{d}{l}$</td>
</tr>
<tr>
<td>Wide profile or tube steel</td>
<td></td>
<td>100-500</td>
<td>6-14</td>
<td>20-30</td>
</tr>
<tr>
<td>Profile steel</td>
<td></td>
<td>200-1000</td>
<td>6-40</td>
<td>18-26</td>
</tr>
</tbody>
</table>
3. Engineering methods

1. Intuition
   - Tradition
   - Professional experience

2. Rules of thumb

3. Basic calculations
   - By ‘hand’
   - Basic modeling

4. Detailed calculations
   - (3D) Computer modeling
   - Detailed insight in performance of parts
4. Shelter development requirements

Main criteria
1. General design conditions
2. Usability
3. Logistics
4. Assembly / Construction
5. Safety
6. Health
5. Structural safety

5. SAFETY

- Burglary / Intrusion
- Fire
  - Flame retardant
  - Combustibility
  - Generation of smoke
- Structural
  - Risk profile & Safety factors (probability of failure)
  - Applied loads (wind / snow / seismic / water / …)
  - Material quality
  - Soil characteristics
  - Foundation
  - Strength
  - Stability (2\textsuperscript{nd} order effects)
  - Stiffness

Anchoring

Joints
Example: Warehouse shelters ("rubb halls")

- Unawareness of (effects of) normative loads
- Underestimation of extreme (wind) loads

- Failure due to assembly mistakes:
  - Anchoring not properly driven in (hard soil)
  - Only half of the anchors are applied
  - Assembled on unlevel surface
  - Stability bracing not (properly) placed in many cases
CRITICAL: ANCHORING AND JOINTS!!!!
Anchor performance in structural safety

Resistance to:

- wind pressure / suction
- Uplift forces and horizontal forces

Warehouse shelter

- 8m span,
- 5m ridge height
- Wind 31 m/s
(10 min average, 10m height, 5y ref. period)
6. Anchoring

Performance indicators

- Soil characteristics
  (Cohesive / Non cohesive)
- Anchor size
  (surface)
- Anchor length / depth / angle of insertion
- Applicability on site? Manually?
- Number of anchors
  (interdependencies when placed closely to each other)
6. Anchoring

Test of Manta Ray Ground anchor

- Sandy Clay
- MR-88 anchor at 50 cm depth (45° - 80 cm length)
- Tractor with telescopic fork lift: > 600 kg (6kN)
6. Anchoring

Example: Haiti 2 Storey Shelter

- 4 m$^3$ concrete (9600 kg) to keep house in position
- Or apply ground anchors (similar holding capacity)
6. Anchoring

Example: Collective Centre

- 4 anchors per footing (total 80 kN)
- Vertical forces: Self weight and snow (downward and outward forces)
- Horizontal forces: Wind suction (uplift) and wind pressure (inward force)

\[
\begin{align*}
H_1 &= 56.8 \text{ kN} \\
V_1 &= 33.4 \text{ kN} \\
\alpha_1 &= 60^\circ \\
D_1 &= 65.9 \text{ kN}
\end{align*}
\]

\[
\begin{align*}
H_1 &= 56.8 \text{ kN} \\
V_1 &= 33.4 \text{ kN} \\
\alpha_1 &= 45^\circ \\
D_1 &= 80.3 \text{ kN}
\end{align*}
\]
7. Joints

Connection Strength & Stiffness

- **Strength of joint itself**
  - Material quality
  - Production quality
  - Joint type

- **Rotational capacity**
  - Free (hinge)
  - Flexible
  - Rigid
7. Joints

Stability

- Excessive deformation leads to unsafe situations
- Stiff planes: bracing / rigid connections
- Stability in 3 planes: xy/yz/zx
- 2nd order effect:
  - loads on already deformed structure

Rigid connections

Bracing
7. Joints

- Examples:
  - Collective centre: rigid connections & 100% hinges
7. Joints

Innovative solutions

• Building regulations and calculation procedures for ‘uncommon’ joint types and materials do not exist.
• Proof of equivalent performance needed:
  • Strength
  • Rotational capacity
8. Conclusions

Structural performance issues for safe shelters

- Lack of appropriate structural norms and calculation methods
  - National building codes are based on regular and permanent buildings
  - Current standards for sheltering provide unclear information for engineers
- Undefined risk profile
- Undefined or unknown level of extreme loads to be expected
  - Underestimation of loads leading to unsafe solutions
  - Overestimation of loads, leading to economic disadvantage
- Unknown material quality of locally available materials
- Unknown production quality of locally produced components
- Unknown construction quality of a locally assembled (self help) shelter
- Lack of specific structural expertise in the field to judge safety and reliability of solutions within a specific context

ACKNOWLEDGEMENT OF ISSUES ABOVE IS ESSENTIAL FOR DEVELOPING SAFE SHELTER STRUCTURES
DEVELOPING SAFE SHELTER STRUCTURES

Thank you!

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