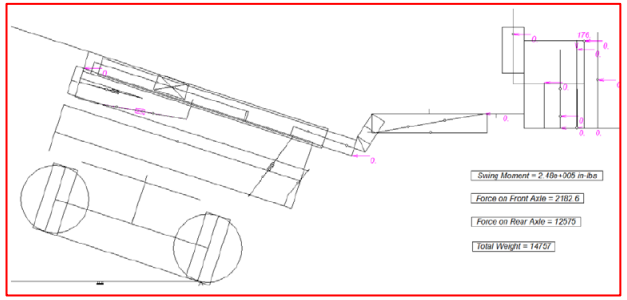
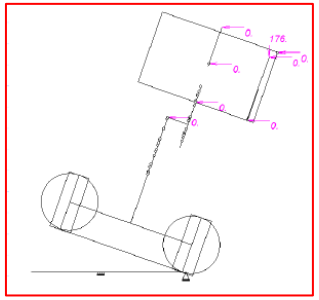
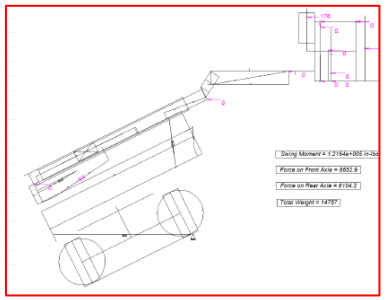
Gradeability analysis of MEWP Machine







Gradeability Calculations - CWT Uphill:

Angle of Inclination: $\theta_{uphill} := \operatorname{atan}(sr_{uphill}) = 17.74\ deg$

Front Axle Normal Force: $N_{front\_axle\_uphill} := F_{front\_axle\_uphill} \cdot \cos(\theta_{uphill}) = 2078.8\ lbf$

Rear Axle Normal Force: $N_{rear\_axle\_uphill} := F_{rear\_axle\_uphill} \cdot \cos(\theta_{uphill}) = 11976.7\ lbf$

Tractive Effort Required to climb Grade:

Front Axle Tractive Force: $F_{front\_axle\_traction} := \min(\mu_{trac} \cdot N_{front\_axle\_uphill}, F_{axle\_motor}) = 1351.2\ lbf$

Rear Axle Tractive Force: $F_{rear\_axle\_traction} := \min(\mu_{trac} \cdot N_{rear\_axle\_uphill}, F_{axle\_motor}) = 3448.7\ lbf$

Total Available Tractive Effort: $F_{trac\_avail} := F_{front\_axle\_traction} + F_{rear\_axle\_traction} = 4799.9\ lbf$

Tractive Effort Required: $F_{trac\_req} := W_{uphill} \cdot (\sin(\theta_{uphill}) + f_{res} \cdot \cos(\theta_{uphill})) = 4778.9\ lbf$

Traction Index - Drive: $TI_{drive} := \frac{F_{trac\_avail}}{F_{trac\_req}} = 1.004$

$Evaluation2 = \text{"pass"}$

Traction Index - Drive: $\mu_{req} := \mu_{min}(N_{front\_axle\_uphill}, N_{rear\_axle\_uphill}, F_{axle\_motor}, F_{trac\_req}) = 0.64$

$\mu_{req} = 0.64$

Required Braking Force:

Front Axle Braking Force: $F_{front\_axle\_brake} := \min(\mu_{trac} \cdot N_{front\_axle\_uphill}, F_{axle\_brake}) = 1351.2\ lbf$

Rear Axle Braking Force: $F_{rear\_axle\_brake} := \min(\mu_{trac} \cdot N_{rear\_axle\_uphill}, F_{axle\_brake}) = 6339.5\ lbf$

Total available Braking Force: $F_{Brake\_avail} := F_{front\_axle\_brake} + F_{rear\_axle\_brake} = 7690.7\ lbf$

Required Braking Force: $F_{Brake\_req} := W_{uphill} \cdot \sin(\theta_{uphill}) = 4497.8\ lbf$

Traction Index - Brake: $TI_{brake} := \frac{F_{Brake\_avail}}{F_{Brake\_req}} = 1.71$

$Evaluation3 = \text{"pass"}$

Minimum Required Friction Co-efficient: $\mu_{req} := \mu_{min}(N_{front\_axle\_uphill}, N_{rear\_axle\_uphill}, F_{axle\_motor}, F_{Brake\_req})$

$\mu_{req} = 0.51$

Gradeability Calculations - CWT Downhill:

Angle of Inclination: $\theta_{downhill} := \operatorname{atan}(sr_{downhill}) = 26.57\ deg$

Front Axle Normal Force: $N_{front\_axle\_downhill} := F_{front\_axle\_downhill} \cdot \cos(\theta_{downhill}) = 7739.4\ lbf$

Rear Axle Normal Force: $N_{rear\_axle\_downhill} := F_{rear\_axle\_downhill} \cdot \cos(\theta_{downhill}) = 5459.9\ lbf$

Tractive Effort Required to descend Grade:

Front Axle Tractive Force: $F_{front\_axle\_traction} := \min(\mu_{trac} \cdot N_{front\_axle\_downhill}, F_{axle\_motor}) = 3448.7\ lbf$

Rear Axle Tractive Force: $F_{rear\_axle\_traction} := \min(\mu_{trac} \cdot N_{rear\_axle\_downhill}, F_{axle\_motor}) = 3448.7\ lbf$

Total Available Tractive Effort: $F_{trac\_avail} := F_{front\_axle\_traction} + F_{rear\_axle\_traction} = 6897.4\ lbf$

Tractive Effort Required: $F_{trac\_req} := W_{downhill} \cdot (-\sin(\theta_{downhill}) + f_{res} \cdot \cos(\theta_{downhill})) = -6335.6\ lbf$

Traction Index - Drive: $TI_{drive} := \frac{F_{trac\_avail}}{F_{trac\_req}} = -1.089$

$Evaluation2 = \text{"pass"}$

Traction Index - Drive: $\mu_{req} := \mu_{min}(N_{front\_axle\_downhill}, N_{rear\_axle\_downhill}, F_{axle\_motor}, F_{trac\_req}) = 0.01$

$\mu_{req} = 0.01$

Required Braking Force:

Front Axle Braking Force: $F_{front\_axle\_brake} := \min(\mu_{trac} \cdot N_{front\_axle\_downhill}, F_{axle\_brake}) = 5030.6\ lbf$

Rear Axle Braking Force: $F_{rear\_axle\_brake} := \min(\mu_{trac} \cdot N_{rear\_axle\_downhill}, F_{axle\_brake}) = 3548.9\ lbf$

Total available Braking Force: $F_{Brake\_avail} := F_{front\_axle\_brake} + F_{rear\_axle\_brake} = 8579.5\ lbf$

Required Braking Force: $F_{Brake\_req} := W_{downhill} \cdot \sin(\theta_{downhill}) = 6599.6\ lbf$

Traction Index - Brake: $TI_{brake} := \frac{F_{Brake\_avail}}{F_{Brake\_req}} = 1.3$

$Evaluation3 = \text{"pass"}$

Minimum Required Friction Co-efficient: $\mu_{req} := \mu_{min}(N_{front\_axle\_downhill}, N_{rear\_axle\_downhill}, F_{axle\_motor}, F_{Brake\_req})$

$\mu_{req} = 0.58$

Gradeability Calculations - Sidehill:

Angle of Inclination: $\theta_{sidehill} := \operatorname{atan}(sr_{sidehill}) = 19.29\ deg$

Left side wheels Normal Force: $N_{left\_side\_sidehill} := F_{left\_side\_sidehill} \cdot \cos(\theta_{sidehill}) = 3389.3\ lbf$

Right side wheels Normal Force: $N_{right\_side\_sidehill} := F_{right\_side\_sidehill} \cdot \cos(\theta_{sidehill}) = 10530.5\ lbf$

Tractive Effort Required to climb Grade:

Front Axle Tractive Force: $F_{left\_side\_traction} := \min(\mu_{trac} \cdot N_{left\_side\_sidehill}, F_{axle\_motor}) = 2203\ lbf$

Rear Axle Tractive Force: $F_{right\_side\_traction} := \min(\mu_{trac} \cdot N_{right\_side\_sidehill}, F_{axle\_motor}) = 3448.7\ lbf$

Total Available Tractive Effort: $F_{trac\_avail} := F_{left\_side\_traction} + F_{right\_side\_traction} = 5651.7\ lbf$

Tractive Effort Required: $F_{trac\_req} := W_{sidehill} \cdot (\sin(\theta_{sidehill}) + f_{res}) = 5166.9\ lbf$

Traction Index - Drive: $TI_{drive} := \frac{F_{trac\_avail}}{F_{trac\_req}} = 1.094$

$Evaluation2 = \text{"pass"}$

Traction Index - Drive: $\mu_{req} := \mu_{min}(N_{left\_side\_sidehill}, N_{right\_side\_sidehill}, F_{axle\_motor}, F_{trac\_req}) = 0.51$

$\mu_{req} = 0.51$

Required Braking Force:

Left side wheels Braking Force: $F_{Left\_Wheel\_brake} := \min(\mu_{trac} \cdot N_{left\_side\_sidehill}, F_{axle\_brake}) = 2203\ lbf$

Right side wheels Braking Force: $F_{Right\_Wheel\_Brake} := \min(\mu_{trac} \cdot N_{right\_side\_sidehill}, F_{axle\_brake}) = 6339.5\ lbf$

Total available Braking Force: $F_{Brake\_avail} := F_{Left\_Wheel\_Brake} + F_{Right\_Wheel\_Brake} = 8542.5\ lbf$

Required Braking Force: $F_{Brake\_req} := W_{sidehill} \cdot \sin(\theta_{sidehill}) = 4871.9\ lbf$

Traction Index - Brake: $TI_{brake} := \frac{F_{Brake\_avail}}{F_{Brake\_req}} = 1.75$

$Evaluation3 = \text{"pass"}$

Minimum Required Friction Co-efficient: $\mu_{req} := \mu_{min}(N_{left\_side\_sidehill}, N_{right\_side\_sidehill}, F_{axle\_motor}, F_{Brake\_req})$

$\mu_{req} = 0.42$

Analysis	Configuration	Case	Load consideration	Analytix data		*Recommended Slope rating	
				Rise/Run [%]	Floor Angle [°]	Rise/Run [%]	Floor Angle [°]
Gradeability	Engine Option	Uphill	1 x m_p = 176 lb	32.2%	17.86	32.0%	17.74
		Downhill	1 x m_p = 176 lb	49.3%	26.26	45.0%	24.23
		Side hill	1 x m_p = 176 lb	37.8%	20.71	32.0%	17.74
		Truck ramp	1 x m_p = 176 lb	32.2%	17.86	32.0%	17.74
	DC Option	Uphill	1 x m_p = 176 lb	32.2%	17.86	32.0%	17.74
		Downhill	1 x m_p = 176 lb	45.0%	24.24	45.0%	24.23
		Side hill	1 x m_p = 176 lb	37.8%	20.71	32.0%	17.74
		Truck ramp	1 x m_p = 176 lb	32.2%	17.86	32.0%	17.74

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Maximum Gradeability Calculation of the machine by using Analytix and Mathcad tools:

- The analyses were carried out for both Engine and DC options.
- Analytix, kinematic tool was used to extract the Axle loads for different machine configurations.
- The Gradeability calculations were done as per standard practice.
- Gradeability of the machine was predicted for the available Traction & Friction forces

Conclusion:

- From the analysis it was found that the maximum Gradeability for;
  - Uphill = 32%
  - Downhill = 45%
  - Sidehill = 32%

  Occurring based on the available Traction and Friction forces.
- Truck ramp case: Uphill gradeability configuration is considered for Truck ramp slope rating.