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A2_6 A flawed Halo

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Abstract
In this paper the forces acting on a Halo installation from the popular 'Halo' series of games is examined to determine the maximum structural flaw size that could occur before critical structural failure and the destruction of the ring. The results imply any flaw of size at least 3.86×10^4m will result in the ring tearing itself apart, a worryingly low value for a structure of this size without some sort of new exceptionally strong material to make such a construct feasible.

Introduction
In the Halo series of games the giant structures known as halos, artificial ring shaped satellites that orbit gas giants, are a key component to the plot. The physical components of the ring are given as a radius of 5000km, width of 322km and a thickness of 22.3km and they sustain 1g gravity by having a rotational speed over 7000m/s [1]. An example of such a structure from the series can be found in figure 1.

However the structure is so massive and yet narrow that it would exert a large force on a itself and if a flaw is present on the structure, either in construction or due to later damage, critical structural failure can occur. This paper will investigate the maximum flaw length that the ring can sustain under its own gravity.

Theory
The equation for fracture mechanics is given as

$$\sigma(f)\sqrt{a} = \sqrt{\frac{2EG(p)}{\pi}} \quad (1)$$

where $\sigma(f)$ is the stress, a is the flaw length, E is Young's Modulus and G(p) is the plastic dissipation term for a ductile material. To calculate this equation the stress must be known which is given by

$$\sigma(f) = \frac{F}{A} = \frac{F}{tw} \quad (2)$$

where F is the force due to the ring's gravity and t and w are its thickness and width respectively. Assuming that the ring experiences the force of its entire mass at the centre of gravity, in other words that the portion of the ring that opposes the rest of the ring's gravitational pull is negligible, the equation

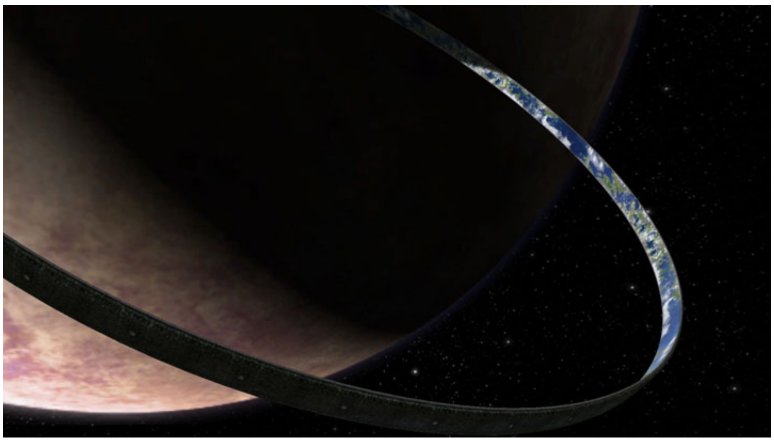

Fig. 1: Image of Halo Installation 04

for gravity and masses of the ring are given as:

$$F = \frac{GMm}{r^2} \tag{3}$$

where M is the mass of the structure as a whole, which can be given by

$$M = \rho V = \rho\pi tw(2r + t) \tag{4}$$

where rho is the density of the ring. Taking a 1m section along the circumference we approximate m to be

$$m = \rho V \approx \rho tw \tag{5}$$

Assuming that the material used in construction is a steel alloy as currently used in shipbuilding the following values can be obtained. The Young's Modulus is found to be 200GPa [2] with a density of $7800kg/m^3$ [3] and a plastic energy dissipation value of $1000J/m^2$ [4]. However it is observed that the Halo constructs have a network of large tunnels and caverns so these gaps will be considered to take up 25% of the volume. Using these values gives the gravitational force of the ring acting on its structure as 1.48×10^{11}N producing a maximum flaw length of 2.99×10^{11}m. This flaw is larger than the ring's circumference! However the more significant force acting on the ring will be the centripetal force

$$F = \frac{mv^2}{r} \tag{6}$$

which has to be considered. This gives a result of 4.12×10^{14}N and a maximum flaw length of 3.86×10^4m. This means only 0.0471% of the ring's structure can be damaged before critical structural failure.

Conclusion

The rings manage to prove that under their own gravitational forces the flaw required would be far larger than the circumference of the ring allows. However this is not the case with the rotational speed included. While the result is a maximum flaw of tens of kilometres, given the size of the ring, this is a relatively low value implying that the ring is at great risk from any form of damage or significant tension. This also shows why a single nuclear explosion from a human vessel in 'Halo: Combat Evolved' was able to completely destroy a structure of this size as it underwent critical structure failure. Of course this can all be negated with the usage of some hitherto undiscovered alloy to increase the resistance of the ring to such events but not under current standard construction methods.

References

[1] `http://www.gamasutra.com/view/feature/129889/halo_science_101.php?page=2`, information on the Halo installation, accessed on 14/11/2012.

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[4] E. Erdogan (2000) Fracture Mechanics, International Journal of Solids and Structures, 37, pp. 171183.