# How does topography affect damage to urban structures including sewer lines?

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## Rationale

Pittsburgh's steep hillslopes create challenges to building and zoning. A better understanding of the influence of hillslope processes on the integrity of urban structures can improve zoning regulations and the prioritization of hillslope stabilization efforts. This can reduce the costs to communities following landslides and soil creep.

## Approach

We measured relationships between gravestones tilt, age, and hillslope gradient in Calvary Cemetery, Pittsburgh, PA. Similar measurements were conducted in residential areas including, house walls, fences, and sidewalks. In Edgewood, we also examined the relations between damages observed in surface structures and known sewer line damage.

## Questions

The questions guiding this research are:

1) Are the rates of hillslope processes in Pittsburgh, as measured from tilted gravestones, able to produce measurable damage to urban structures over a century?
2) Do hillslope processes affect urban structures in residential areas with a similar severity to that observed from tilted gravestones?
3) Does Pittsburgh's rugged landscape affect the amount of damage to surface structures and sewer systems?

## Findings

The goal of this work was to explore the factors that damage surface and subsurface urban structures. We measured damaged structures, topographic, land-cover, and socioeconomic parameters in Pittsburgh, PA, where buildings and sewer lines are built on steep hilly terrain. The age of structures is often older than 100 years.

We first explored the effect of soil processes on urban structures by measuring the tilt of gravestones in a 170-year old cemetery. In this setting, where gravestones provide excellent time constraints and similar structure (shape and size), our measurements show that the amount of gravestone-tilt depends on the slope and the age of the gravestone (Fig. 1). In Pittsburgh, this rate of tilt appears fast enough to progressively damage urban structures over decades to centuries.

In residential areas, where we measured tilted and fractured structures (walls, fences, stairs, sidewalks), the connection between slope and structure damage is not clear (Fig. 2). In sample areas, the severity of damage decreases as the property value increases. In these areas, the influence of soil processes seems to be counteracted by differences in the design and type of structure as well as maintenance efforts to repair damage.

In Edgewood, PA, where data on the integrity of the sewer system is available, the intensity of damage to sewer lines correlates with damage to surface structures such as tilted walls and fences (Fig 3). This relation suggests that leaks in water infrastructure can increase soil movement and/or that areas where soils move contribute to sewer damage.

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## Figure 1:

(A) Topographic slope vs gravestone tilt. (B) Gravestone age vs. tilt. Bars represent standard error of each point. Note points represent binned mean values of the dataset.

## Figure 2:

(A) Amount of damage to urban structures vs. topographic slope (note the low correlation and difference in damage scales). (B) Mean damage class in urban structures per neighborhood vs. the mean house value. Damage to Surface Structures is a subjective metric where the value of one indicates low damage. Note points represent binned mean values of the dataset.

## Figure 3:

The intensity of damage to sewer lines vs. (A) magnitude of damage to surface strictures, and (B) tilt of urban structures such as walls and sidewalks. Sewer defect intensity is a subjective metric measured on a one to five scale, where one is low damage and five is high damage. Note points represent binned mean values of the dataset.

Figure 1

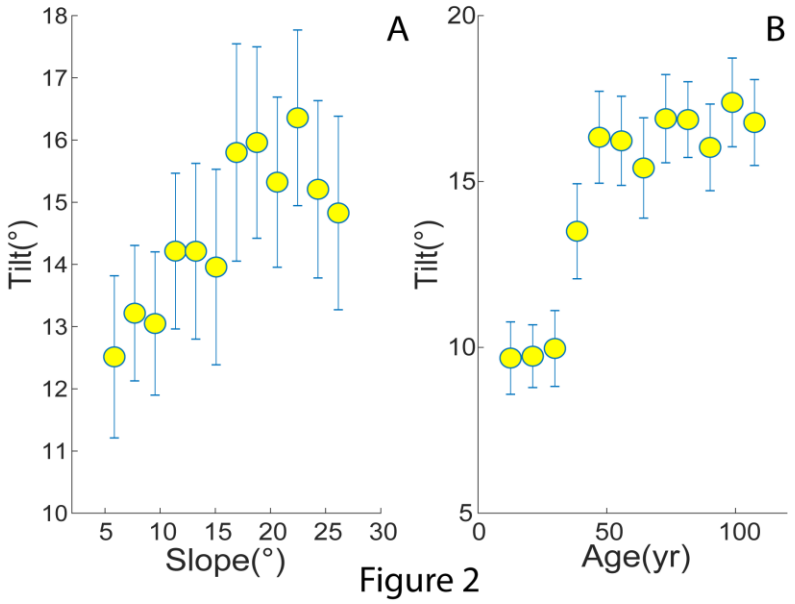



Figure 2

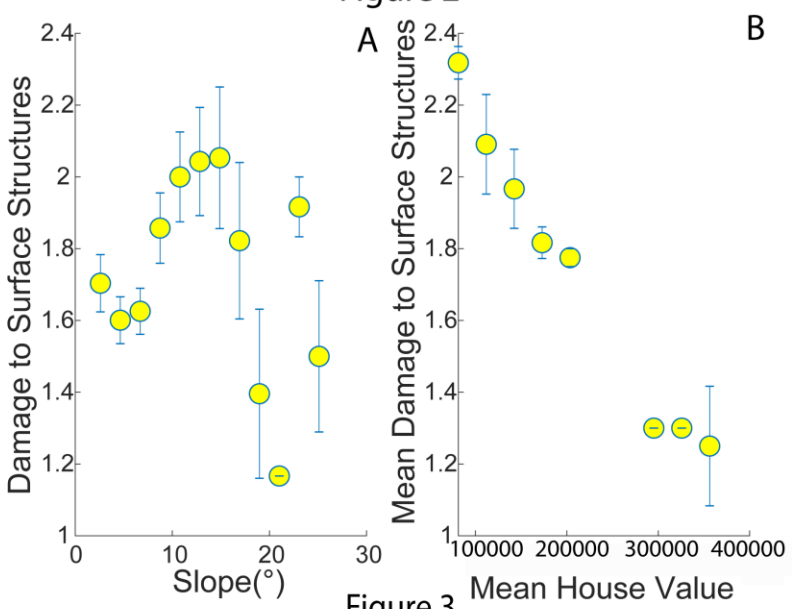
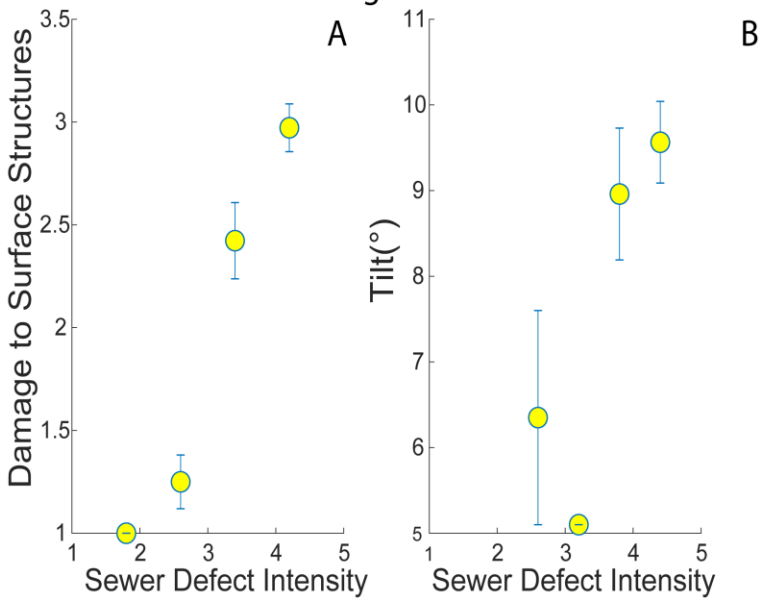



Figure 3

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## Implications

- Analysis of tombstones suggests that hillslope processes (e.g., soil creep) progressively tilt urban structures over a century.
- Analysis of damaged structures in residential neighborhood suggests that the magnitude of damage is not clearly related to topographic slope or the age of structures, probably because this influence is masked by maintenance efforts, the sample size is small, or because the structural differences between tombstones and residential structures makes them sensitive to different processes.
- The relationship between damage to sewer and damage to surface structures suggests that damaged surface structures can help identify areas where the sewer system is prone to damage. More data is needed to further test this approach.
- The relationship between damaged surface structures and damaged sewers should be accounted for in prioritization of sewer maintenance efforts. Further, design of future sewer systems should avoid if possible, areas where landslides and soil creep are more likely to occur.

*Urban structures are progressively affected by hillslope processes and this relationship may be used to examine where increased damage to sewers from processes such as soil creep might occur.*

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