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Ice Load Effect on Martian Buildings

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Abstract: Humanity has long been in pursuit of new habitats, and in this direction, the desire to establish colonies based on technological advancements has been increasing. In this context, the National Aeronautics and Space Administration (NASA) has been sending unmanned spacecraft to Mars since 1970. For the structures to be built on Mars, it is necessary to study structural loads similar to those on our planet. Therefore, particular attention needs to be paid to structural loads on Mars, especially ice loads and how these loads vary across different regions of the planet. Specifically, the distribution and grading of Mars-specific ice loads are the focus of this study. The research has focused on how ice loads used in the design process for structures to be built on Mars differ across regions. Consequently, it has been determined that especially in the polar regions of Mars, ice loads are an important parameter to consider in structural design, while subterranean ice around the equator is critical for excavation works and anchoring applications. These findings provide critical information that will aid in making decisions in the process of constructing sustainable structures on Mars.

Keywords: Mars, Design loading, Ice load, NASA, Multiplanetary life

Mars Gezegeninde Buzun Varlığı ve Yapılara Etkisi

Özet: İnsanlık uzun yıllardır yeni yaşam alanları arayıp bulmaya çalışmakta ve bu doğrultuda teknolojik gelişmelere dayalı koloni kurma isteği de artmaktadır. Bu kapsamda, Ulusal Havacılık ve Uzay Dairesi (NASA) 1970 yılından itibaren Mars gezegenine insansız uzay araçları göndermektedir Mars'ta inşa edilecek yapılar için, gezegenimize benzer yapısal yüklerin araştırılması gerekmektedir. Bu nedenle, Mars gezegeninde dikkate alınması gereken yapısal yükler arasında özellikle buz yükü ve bu yükün gezegenin farklı bölgelerinde nasıl değişeceği merak edilmektedir. Özellikle, Mars'a özgü buz yükleri ve bu yüklerin gezegenin farklı bölgelerindeki dağılımı ve derecelendirmesi bu çalışmanın odağını oluşturmaktadır. Araştırmalar, Mars gezegeninde inşa edilecek yapılar için tasarım sürecinde kullanılacak buz yüklerinin bölgelere göre nasıl farklılaştığına odaklanmıştır. Sonuç olarak, özellikle Mars'ın kutup bölgelerinde buz yüklerinin yapı tasarımında önemli bir parametre olarak dikkate alınması gerektiği, ekvator ve çevresindeki yer altı buzlarının ise kazı çalışmaları ve ankraj uygulamalarında kritik öneme sahip olduğu tespit edilmiştir. Bu bulgular, Mars'ta sürdürülebilir yapılar inşa etme sürecinde kritik kararlar alınmasına yardımcı olacak bilgiler sağlamaktadır.

Anahtar Kelimeler: Mars, Tasarım yükü, Buz yükü, NASA, Çok gezegenli yaşam

1. Introduction

Today, many developed countries and private companies are engaged and try hard to be successful in the space race. Sending uncrewed vehicles to Mars and Moon that are generally at the fore continues. In first place, mankind set the Moon as its target in the space race. Moon has come to the fore since it is the satellite of Earth and is the closest celestial body to Earth. It was the Soviet Union's (USSR) Luna 2 spacecraft that first successfully reached the surface of the Moon. Although the USSR continued its research by sending other Luna vehicles to orbit or the Moon, the United States joined this race by sending many crewed spacecraft to the Moon with the Apollo mission program in 1968. Apart from the USSR and the USA, China, India, Japan, Israel, Russia, the United Arab Emirates (UAE), Luxembourg, South Korea and Italy have participated in Moon studies with different missions

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since 1968. Although Moon was more in the foreground than Mars in the early days, it is disadvantaged in terms of the lack of atmosphere and the resulting high temperature difference between day and night and the amount of water it contains. For all these reasons, mankind has shifted its research and space missions to the planet Mars.

Mars remained unknown, inaccessible and dark for mankind for many years. Mars missions were implemented by the USA and USSR in the 1960s, but but no significant progress was made until 1975. Viking 1&2 spacecraft, sent to Mars as part of the Viking project launched by NASA in 1975, successfully landed in 1976. Viking 1 continued its mission until 1978 and Viking 2 until 1980 (NASA, 2024). In the following years, mission missions became more frequent, and the Sojourner spacecraft was sent to Mars with different missions by Sojourner in 1996, Spirit & Opportunity in 2003, Phoenix in 2007, Curiostiy in 2011, InSight in 2018 and Perverance in 2020, respectively. A view of Mars-Sequoia area by Mars Curiosity Rover is as shown in Figure 1 (URL-1). Curiostiy Rover detected CO2 (95.9%), Ar (2%), N2 (1.9%), O2 (0.14%) and CO (0.016%) gases on the planet Mars respectively in 2012 (URL-2). In addition, another mission is planned by the same institution to collect surface samples from Mars in 2027.

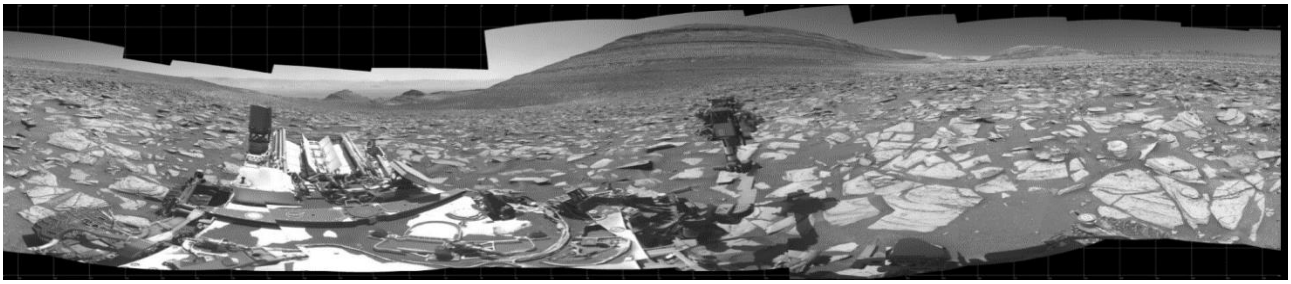


Figure 1. Curiosity’s Navcams View the Area Around 'Sequoia'

Over 50 missions to Mars have been carried out to provide a relative understanding of aspects of Mars that can help scientists to carry out innovative studies and projects (Soureshjani et al, 2023). As a result of these studies, it would not be economical to take the materials to be used for low-rise buildings for colonization of Mars from Earth (Toklu, 2000). Thus, Petrov and Ochsendorf (2005) proposed a reliable hybrid Mars base using inflatable and on-site structures. It is an undeniable fact that procuring the materials to be used in building construction from materials found on Mars will be beneficial both in terms of time and economy. However, the regions where colonization will be determined should be chosen carefully. Because subsurface ice was discovered in studies conducted on the planet Mars (NASA, 2023). After this discovery, NASA started to prepare a subsurface water ice map to determine which region of Mars to travel to on the first manned trips. For this, Mars Reconnaissance Orbiter (MRO) and Mars Odyssey orbiter, to locate water ice that could potentially be within reach of astronauts on the Red Planet (NASA, 2024). All these developments will enable the design load to be reached by determining both the 'in situ resource utilization' of water and the thickness of the ice on the structures.

The first stage in designing buildings is to determine the loads. Accurate and realistic determination of loads is of great importance on the gravitational planet Mars, as it is on Earth. Soureshjani et al, (2023) tried to determine Mars payloads. He made suggestions regarding some loads. However, especially as stated by NASA (2023), it is understood that the presence of ice should be taken into consideration both in the selection of the region where spacecraft land and in the design of structures to be built on the planet Mars by shifting research to regions without the presence of ice. Precisely determining and mapping the surface and subsurface ice on Mars will enable astronauts to land in safe areas and will allow us to determine the ice load to be considered in the structures to be built in the coming years. Therefore, in this study, it is aimed to determine the effects of ice load on the structure according to the surface and subsurface ice areas on the Martian surface map by revealing the ice load.

2. Material and Method

Detection of ice masses existing on the planet Mars is made with radar sounding data. These studies have identified many mid-latitude glacier-like forms on the planet as well (Karlsson et al., 2015). The forms discovered in mid-latitudes were estimated with 25% uncertainty by Levy et al. (2014). In their study, they tried to determine the ice volumes according to concentric crater fill (CCF), lineated valley fill (LVF), and lobate debris aprons (LDA) methods. The amount of ice discovered at latitudes of ±30 and 50 is an important water reservoir that can be extracted by surface drilling in the future. Apart from all these studies, Berman et al. (2021), Joseph (2023), Garvin et al. (2024), Tang et al. (2022), Yoldi et al. (2022), Riu et al. (2023), Schörghofer (2021) cunducted studies using methods about the presence of ice on the surface and subsurface of the planet Mars and tried to reveal the amount, location and stability of ice. They also obtained approximate values with different drilling and remote sensing techniques. Besides, Phoenix Mars Lander, managed to take sample pieces from the water ice in the Martian soil on July 31, 2008 (NASA, 2008).

In this study, the study area was considered as the entire planet Mars, including the upper Gediz valley and craters of the Gale crater at 4.5895 S, 137.4417 E according to Mars coordinate system. The visible Mars map of the planet is shown in Figure 2 (URL-3).

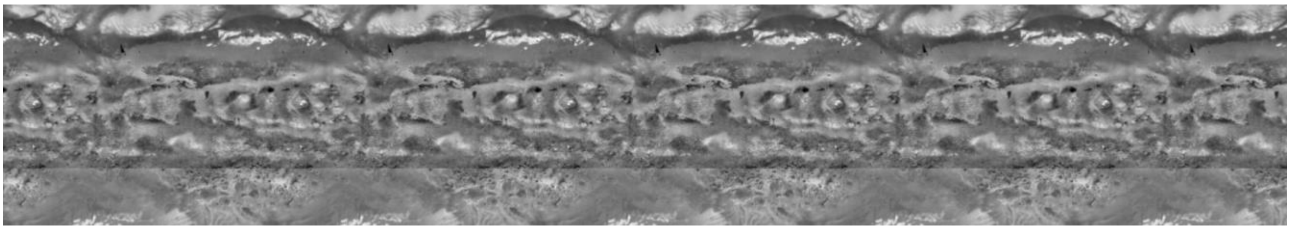


Figure 2. Mars visible map

Akgül and Suphi (2022) used the CRISM sensor as remote sensing data on the MRO satellite that was launched from the Cape Canaveral base in the United States on 12.08.2005 and entered Mars orbit on 10.03.2006. All the features of the sensors related to water and ice on the satellite are given below in Table 1.

Table 1. MRO instruments and features (NASA, 2022)

Instruments	Features
MCS	Monitoring changes in the atmosphere
SHARAD	Water ice research.
CRISM	Identification of minerals

In the light of the data obtained with sensors such as MCS, SHARAD and CRISM, although the ice effect on Mars dust is negligible, the presence of water ice reservoirs were detected in some areas very close to the surface. Visible ice layers can be found even at 50 cm excavations. Therefore, the ice effect should be taken into consideration in the subsurface excavations on Mars. Water ice at low latitudes have a structure that constantly changes according to the seasons. In foundation or anchor excavations for Martian structures, ice effect should be taken into consideration both laterally and vertically. Following the recent discoveries by the European Space Agency (ESA), the ever-changing presence of ice can create gaps around the structure anchor/foundation, creating discontinuities beneath the Martian surface. The waterways that represent the natural functioning under the crater and feed the glaciers in the Martian craters are shown in Figure 3 (Fraeman et al., 2020).

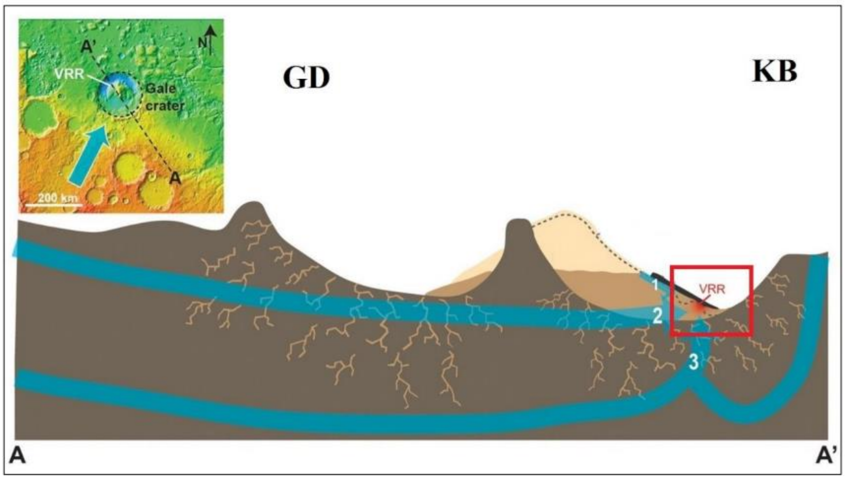


Figure 3. Crater waterways

It is known that the gravity of the planet Mars is 38% of the gravity of the Earth. This reduces both the total weight of the structure and the gravity of each design load. Compared to other planets, the gravity of Mars is closer to Earth's gravity. For example, the gravity on the moon is one-sixth of the Earth's gravity.

2.1. Design Loads

In addition to vertical loads, horizontal loads are based on the experiences and research obtained as a result of a certain period of time on Earth. Most countries have created their own design codes and load combinations related to their geography. The necessity of our planet and the occurrence of ground movements or different natural phenomena have forced researchers to consider some special loads other than horizontal loads (earthquake, wind, etc.) and vertical loads in the design.

Loads on earth consist of dead load, live load, snow load, earthquake load, wind load, etc. When these loads come together, load combinations are formed. The load combinations of the ASCE 7-10 'Minimum design loads and associated criteria for buildings and other structures' regulation are as follows (ASCE 7-10, 2017).

$$1.4\ D \tag{1}$$

$$1.2\ D+1.6\ L+0.5\ S \tag{2}$$

$$1.2\ D+1.6\ S+0.5\ W \tag{3}$$

$$1.2\ D+1.6\ S+L \tag{4}$$

$$1.2\ D+1.0\ W+1.0\ L+0.5\ S \tag{5}$$

$$1.2\ D+1.0\ E+1.0\ L+0.2\ S \tag{6}$$

$$0.9\ D+1.0\ W \tag{7}$$

$$0.9\ D+1.0\ E \tag{8}$$

where D is the dead load, L is the live load, S is the snow load, W is the wind load and E is the earthquake load.

The effect of ice, which is not taken into consideration in the design load combinations on Earth, but is found both on the surface and subsurface in the polar regions of Mars and around the equator, on Martian structures was investigated.

2.1.1. Ice Load

Ice load is not included in many countries' regulations. It is mostly represented as snow load in the standards of the countries. However, the presence of ice in the polar regions of Mars is clearly noticeable in recent discoveries on the planet. Schiff and Gregg (2022) found ice-rich deposits on north-facing slopes along 40 N, 250 E. Son et al. (2023) stated that while ice presence changes seasonally in low latitudes, the change in ice presence in high latitudes is less. However, the presence of ice at low latitudes has also begun to be revealed.

The presence of ice in the northern polar region is shown in Figure 4 (NASA, 2023). These layer thicknesses are measured by the Shallow Radar instrument (Credit: NASA/JPL-Caltech/University of Rome/SwRI).

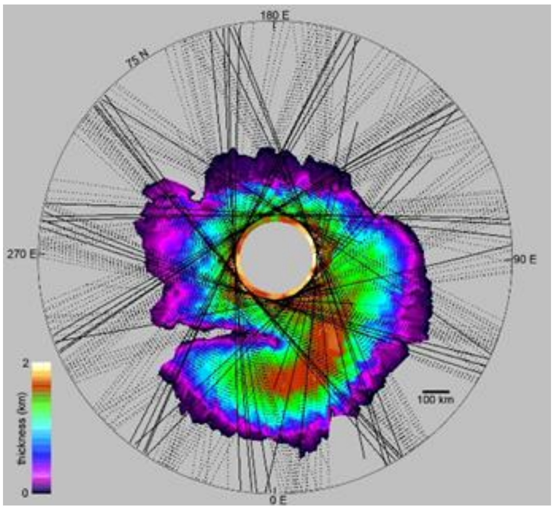


Figure 4. The thickness of the north polar layered deposits on Mars

Ice load may vary depending on regions or ice thickness. As on Earth, the ice load on MARS can be determined in 3 different ways as equatorial, mid-latitude and polar regions. Ice load on Earth is calculated as;

$$L_I = k\sqrt{d} \times g_m \tag{8}$$

where L_I (N) is the ice load, k is a constant, d thickness (mm) and g_m (m/s^2) is the gravitational acceleration of Earth and m (kg) is the mass. This equation applies only to surface structures. It is considered as a layer covering the structures, especially in high altitude regions. Equation number 9 is used especially in electricity transmission lines and electricity distribution networks. However, in order to determine the ice load to be used on the planet Mars, spacecraft must be produced resistant to weather conditions to operate in the region where ice is present. Today, spacecraft cannot approach the polar regions of the planet Mars.

3. Findings and Discussion

In the discovery made by ESA probe, a possible dusty ice layer was discovered at the equator of Mars, apart from its poles, as shown in Figure 5. Buried beneath the planet's equator, this layer of dusty ice is thought to contain enough water to cover Mars in an ocean between 4.9 to 8.9 feet (1.5 to 2.7 meters) deep. Such a large volume of ice deposit has never been found outside the poles (URL-4).

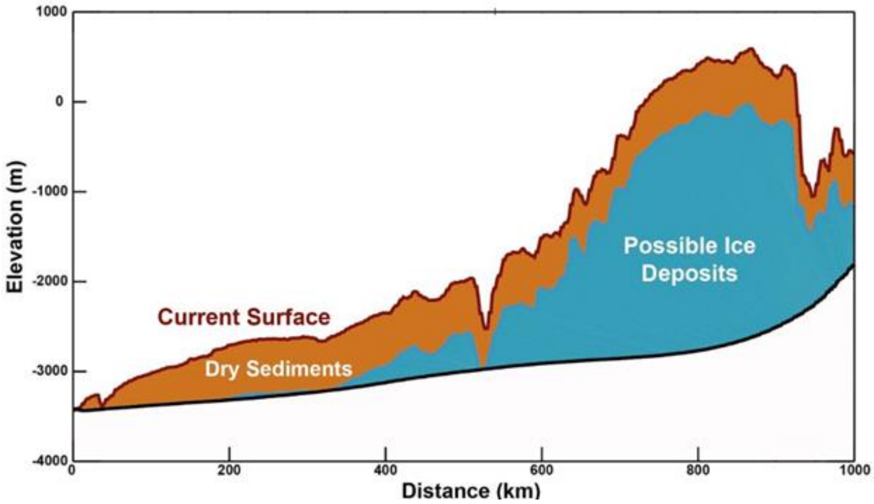
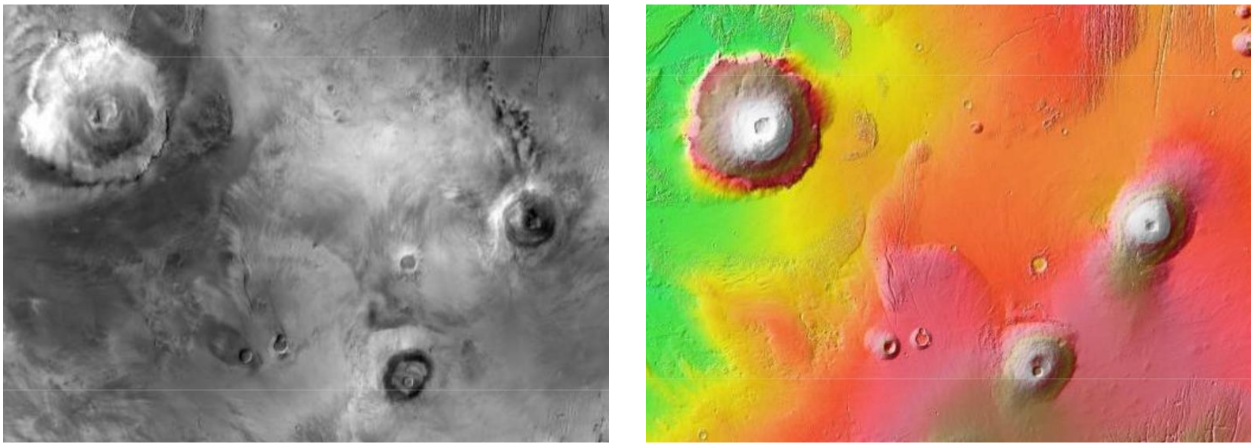


Figure 5. Possible ice thickness in the equatorial region (ESA).

As seen in Figure 5, the possible ice deposit is seen as a result of the discovery made by ESA. This ice deposit is covered with dry sediments and the top layer of Martian dust. This ice deposit, which retreats in summer months, approaches the surface during winter. Another different situation is seen in the crater. Olympus Mons, the highest point of the planet Mars, and its surroundings (Home of the Greek gods) are seen in Figure 6.



(a) (b)

Figure 6. Mars Olympus Mons and its surroundings (18.4N,134W) a) Elevation map b)Visible map

There are subsurface ice deposits at different points of Mars. Studies to date have revealed that these ice deposits are water ice, not carbon dioxide. However, how these ice deposits formed has not been fully explained. Representing the load of ice is quite complex. Especially on the planet Mars, there is ice presence both at the surface and subsurface. However, these ice deposits are covered with Martian dust and drilling works are still ongoing regarding the depth of the ice deposit. Therefore, except for some craters on the surface, as seen in Figure 6, it does not seem possible today for the ice covered with Martian dust at the equator (L_{IE}) and middle latitudes (LI_M) to create a load on the structure

(Equations 10 and 11). In the facilities to be established in the polar regions, the ice load on the structure can be used as in Equation 9, taking into account the acceleration of gravity on Mars.

$$L_{IE} \approx 0 \tag{10}$$

$$L_{IM} \approx 0 \tag{11}$$

However, there is a high probability that ice deposits may be located very close to the surface of the Martian regions where the structure will be built or established. More detailed mapping of ice deposits on Mars will be of great importance in future research and colonization.
It is known that a space rock hitting the Amazonis Planitia region of Mars caused a 4.0 magnitude marsquake on the planet Mars. Researchers have observed that the epicenter of the earthquake and the craters formed overlap each other. They also observed ice around the 150-meter diameter crater formed on the surface of the planet Mars (NASA, 2021). Although displacement of the ice was not observed, they photographed that when the space rock hit the planet Mars, the underground ice was shaken and some of it became visible on the surface (Figure 7).

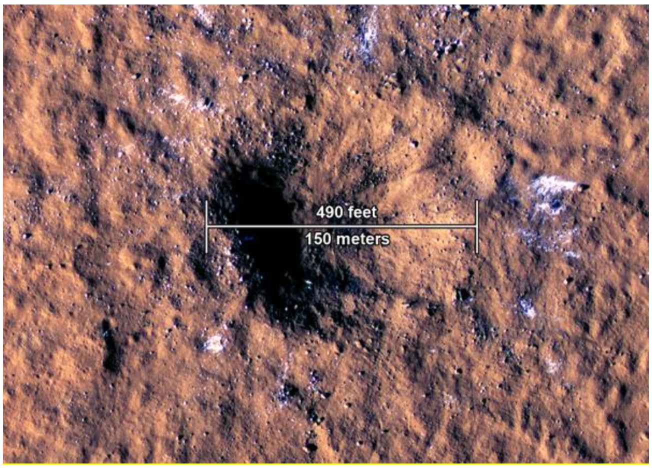


Figure 7. The impact crater, formed Dec. 24, 2021, by a meteoroid strike in the Amazonis Planitia region of Mars (Credit: NASA/JPL-Caltech/University of Arizona)

4. Conclusions

Mankind aims to use the necessary materials in the construction of Martian structures in order to colonize the planet Mars. However, the planet Mars has not yet gone beyond being a very unknown planet for humanity. With the developing technology and research and investments made in recent years, some important and remarkable data about Mars has started to be obtained.

Moving mankind to Mars brings with it the need for shelter. Today, it is very difficult to design Mars structures that can meet the need for safe and permanent shelter and to determine the loads that can affect these structures. In this study, unlike Earth, the 'ice load‘, which is a design load that can be considered in the structures to be built on the planet Mars, and the changes that may occur as this ice load varies according to the latitudes of Mars, were researched. The results obtained are as follows;

- Ice deposits, ice masses that can be seen with the naked eye at the surface in the polar regions of the planet Mars (especially in the south polar circle), are mixed with dust at different depths of subsurface around the equator and in mid-latitudes. After dust storms, surface ice becomes difficult to see with the naked eye, especially in the Arctic Circle.

- The margin of error of the data obtained through remote viewing is an undeniable fact. Therefore, more accurate and realistic results will be achieved with more uncrewed vehicles to be sent to Mars in the coming years.
- Design loads and load combinations can be determined in the light of many years of experience. More accurate results can be obtained by observing the ice load for many years and monitoring the direction of ice flow and the thickness of the layers that may form on Martian surface over time.
- Different ice load coefficients can be determined according to the regions of the planrt Mars, where new ice masses are discovered every day, and structural loads can be applied more easily and transparently by preparing load maps according to latitudes or craters.
- Martian weather conditions should be better understood and the effects of structural load combinations should be observed.
- The spacecraft sent to the planet Mars by the international community cannot approach these regions because they are not capable of operating in extremely cold environments, especially in the polar regions. There is a tendency for underground ice in low latitudes to be used only as a water source for astronauts reaching the planet Mars. Again, there is no research on the use of craters in low latitudes and ice in high altitudes as building materials.
- It is known that the thin atmosphere of the planet Mars and the effect of wind affect ice formation both on Earth and on the planet Mars. In the literature, Soureshjani et al. (2023) published their research on wind load.

It is an undeniable fact that time and new research are needed to examine new load combinations and structural loads for the planet Mars.

Conflict of Interest

The author declare that they have no conflict of interest.

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